TECHNICAL REPORT S-70-1

ACOUSTIC SUBBOTTOM PROFILING SYSTEMS A STATE-OF-THE-ART SURVEY

by

R. T. Saucier

April 1970

Sponsored by U. S. Army Engineer Division, Lower Mississippi Valley

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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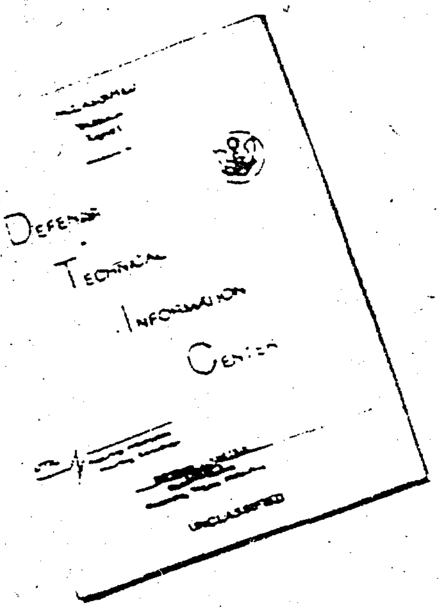

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ARMY-MRC VICKSBURG, MISS.

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FOREWORD

This study was authorized by a letter, dated 12 July 1967, from the Division Engineer, U. S. Army Engineer Division, Lower Mississippi Valley (LMVD), to the Director, U. S. Army Engineer Waterways Experiment Station (WES), subject "Status of Soils Division Projects for MRC and LMVD for FY 1967 and Request for Funds for Projects for FY 1968."

The conduct of this study and the preparation of this report were accomplished by Dr. R. T. Saucier of the Geology Branch, Soils Division, WES, during the period August 1968 to December 1969. Direct supervision of this study was provided by Dr. C. R. Kolb and Mr. W. B. Steinriede, Jr., of the Geology Branch; general supervision was provided by Mr. J. P. Sale, Chief of the Soils Division.

Director of the WES during the conduct of this study and the preparation of this report was COL Levi A. Brown, CE. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

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NOTATION

Since many of the symbols and abbreviations used in this report are not widely used outside the fields of physics and acoustics, the following list is included for reference:

AC	alternating current
cps	cycles per second
db	decibels
fps	feet per second
J	joules
kcps	kilocycles per second
msec	milliseconds
psig	pounds per square inch gage
v	volts
w	watts

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
cubic inches	16.387064	cubic centimeters
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
knots (nautical miles per hour)	1.852	kilometers per hour

SUMMARY

A literature survey was conducted, data sheets were examined, discussions were held with manufacturers and users, and field tests were performed to assess the current status of acoustic subbottom profiling systems. Emphasis was placed on establishing operating principles, methods of survey operation, inherent capabilities and limitations, environmental restrictions, and availability, particularly from the standpoint of conditions and problems in the Lower Mississippi Valley area.

Acoustic profiling systems are commonly classified according to the method by which the sound energy is produced, i.e. piezoelectric and magnetostrictive transducer pingers, electromechanical-type transducers or boomers, sparkers and arcers, gas guns, air guns, and others. The various sound sources achieve different degrees of resolution and penetration, largely because of differences in the frequency spectrum of the acoustic energy they generate. However, because of an inherent inverse relationship between degree of resolution and depth of penetration, it is impossible to achieve both high resolution and deep penetration with any acoustic system--a compromise is always necessary.

Depending upon the sound source used, either transducers or hydrophones of various designs are used to detect the acoustic signals reflecting from subbottom horizons. Graphic recorders of either helix or stylus types, using either wet or dry paper, are used with nearly all acoustic profiling systems; however, magnetic-tape recording and digital conversion for signal processing and playback also are being used with the more elaborate systems.

Interpretation of acoustic subbottom profiles requires an awareness of and possible corrections for variations in horizontal and vertical scales caused by several factors such as variations in the sound velocities of the sediments. Recognition of complicating multiple reflections, an understanding of why various horizons may or may not produce reflections, and recognition of certain characteristic "signatures" are also important in record interpretation.

Operational considerations such as size and weight of equipment, power generation requirements, and possible need for towed transducer vehicles are important in system selection for a particular survey. Environmental considerations such as water salinity and water depth can also influence system selection.

Previous applications and potential capabilities of acoustic profiling systems for the detection of buried erosion surfaces, correlation between

borings, construction materials surveys, bedrock surveys, fault detection and delineation, and reservoir sedimentation studies are discussed. Thoughts and observations are advanced regarding the relative advantages of purchasing or leasing acoustic systems and contracting for geophysical survey services.

ACOUSTIC SUBBOTTOM PROFILING SYSTEMS

A STATE-OF-THE-ART SURVEY

PART I: INTRODUCTION

Purpose

1. This state-of-the-art survey was conducted to provide an up-to-date assessment of the variety, nature, utilization, and operational capabilities and limitations of acoustic subbottom profiling systems. Although the entire field of overwater continuous seismic reflection profiling was assessed, particular attention was devoted to those systems which appear to be applicable to the geological problems and conditions occurring in the Lower Mississippi Valley, i.e. engineering-geologic investigations in shallow, fresh to brackish water bodies.

Scope

2. Most of the information in this report pertaining to the classification, operational characteristics, and capabilities of the acoustic systems was obtained as a result of a comprehensive literature survey. Additional information, valuable in providing a more thorough tabulation of available systems (table 1), was obtained from brochures, catalogs, and data sheets supplied by manufacturers and sales representatives.

3. Project funds and scheduling permitted brief personal contacts with a selected number of commercial firms, governmental agencies, and university-affiliated research organizations in the New Orleans-Houston-Galveston-Corpus Christi areas of Louisiana and Texas. In addition, a trip was made to San Diego, California, to contact several manufacturers and to discuss the field of acoustic profiling with personnel of the U. S. Naval Undersea Research & Development Center and the Scripps Institution of Oceanography.*

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* Complete names and addresses of all firms, agencies, and organizations mentioned in this report are contained in Appendix A.

4. Reports including the results of various acoustic profiling surveys were obtained for the purpose of this study from several Corps of Engineers (CE) district offices from whom surveys had been conducted. In addition, the writer was able to conduct a brief field test using a pinger system operated by the U. S. Army Engineer District, New Orleans (NOD). This report also includes discussions of and evaluations resulting from a survey made with a boomer system in a project supervised by the writer for the U. S. Army Engineer District, Mobile (MDO).

5. The intent in this investigation was to define the basic operational acoustic systems through a representative sampling process. No attempt was made to identify or evaluate all available models or units or necessarily to tabulate complete operational characteristics on any one unit. Although it is felt that the survey of the field has been reasonably thorough, it is quite probable that certain less well known models or manufacturers have been overlooked. The numerical data presented in table 1 and elsewhere in the report were obtained primarily from published sources; no attempt was made to verify these data with the manufacturers or operators.

PART II: PRINCIPLES OF OPERATION

The Basic System

6. All continuous subbottom profiling systems are dependent upon generation of relatively low-frequency, regularly pulsed acoustic energy (sound) and the detection and recording of that part of the sound output that is reflected back from boundaries between subbottom materials of different acoustic impedance.[1] The acoustic energy is introduced directly into the water beneath or behind a moving boat. Reflections resulting from each separate sound pulse are detected and are automatically correlated and successively recorded on a moving-paper or chart recorder;[2] hence, a cross section with constant scales is produced (fig. 1). The horizontal scale is determined by

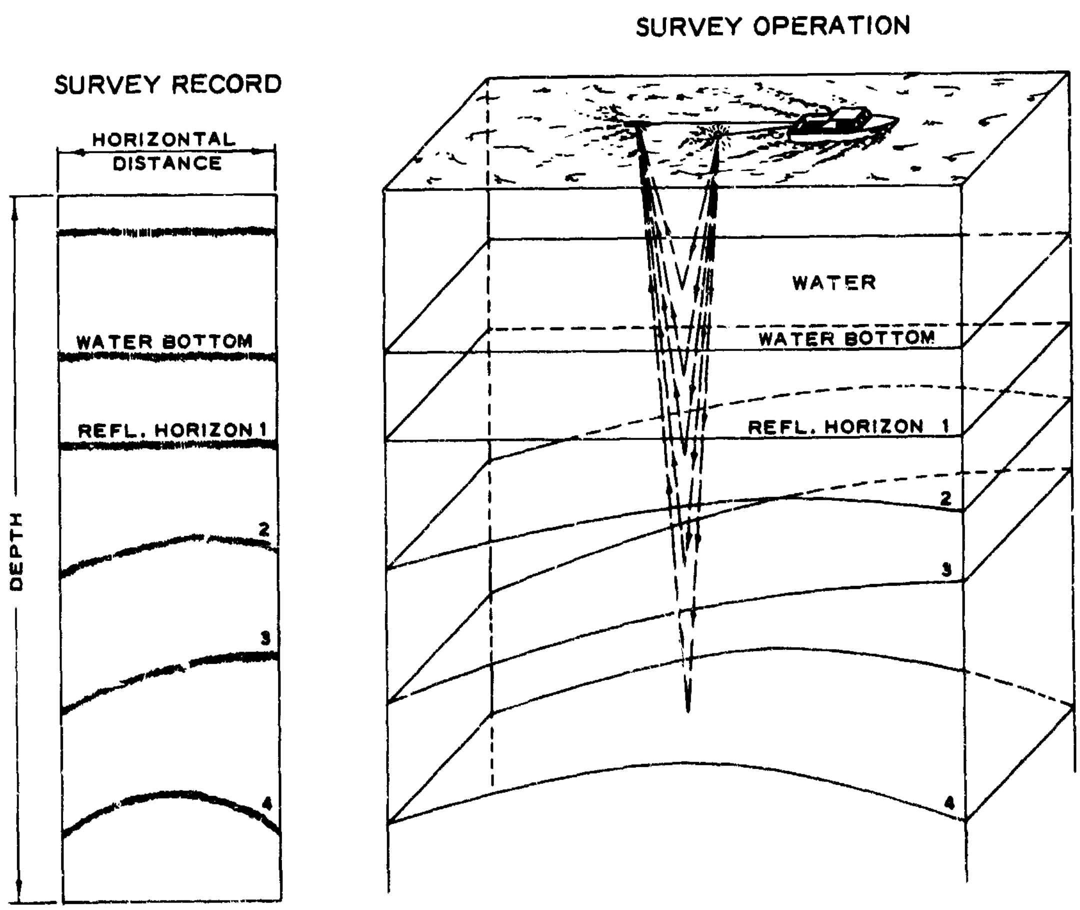

Fig. 1. Operating principle of a typical acoustic subbottom profiling system (modified from reference 3)

the speed of the boat, and the vertical scale is controlled by the travel time of the sound waves in the water and sediment or rock.

7. As illustrated in Fig. 2, all acoustic subbottom profiling systems

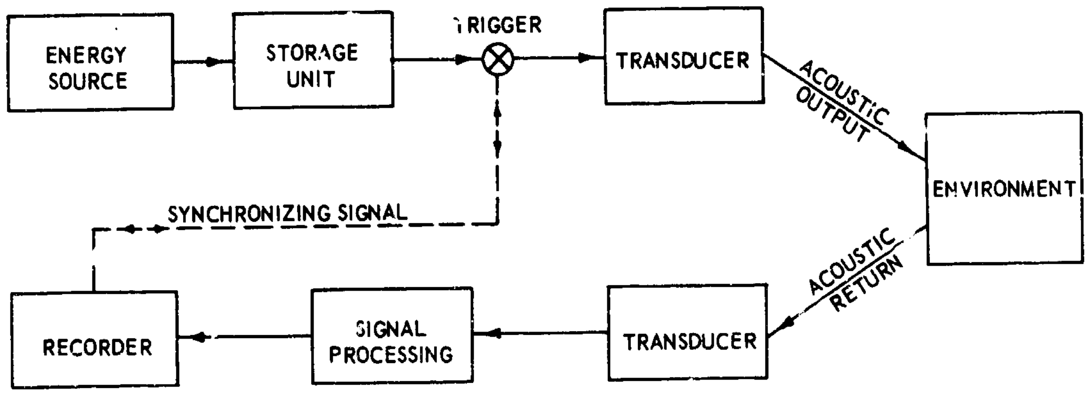

Fig. 2. Basic components of any acoustic subbottom profiling system (taken from reference 4)

have certain essential functional components. The systems differ substantially only in regard to the type of energy or sound source employed, and the systems are classified and commonly named accordingly (see Part III of this report). Other components such as transducers and recorders vary relatively little from one system to another and usually only in regard to design. Although some interchangeability of components consequently is possible (e.g. a given hydrophone may be used with several different sound sources), this is not a normal or recommended procedure. The most satisfactory and efficient systems in current use are the result of considerable experimentation and testing aimed at selecting components that yield the highest possible electronic and/or acoustic compatibility.

History of Development

8. The first realization that echoes or reflections of acoustic energy could be obtained from subbottom layers or horizons was made only about 30 years ago.[2] At that time, shallow subbottom layers were sometimes detected under ideal conditions in shallow-water areas using echo sounders and graphic recorders. It was not until about 20 years ago that it was discovered that penetrations of several hundred feet could be obtained in deep

water using high explosives as an energy source.

9. Although several systematic acoustic subbottom surveys were made using modified echo sounders in shallow coastal or inland water bodies during the late 1940's and early 1950's,[5] the first instrument designed specifically for obtaining subbottom penetrations and reflections was not operational until about 1954. This instrument, built by the Magnolia Petroleum Co. (now Mobil Oil Corp.), is the now-famous Sonoprobe.[6] During the succeeding decade, all of the major energy sources now in use and the systems designed around them were developed and made operational.

10. At the present time, hundreds of acoustic subbottom profiling systems have been manufactured and are being used throughout the world. As indicated in table 1, at least 12 systems (or most of the major components of a system) are commercially available. These systems generally are the smaller, lower powered, high-resolution, shallow-penetrating systems useful for detailed studies of stratigraphy and sedimentation rates and patterns. Intermediate-sized systems capable of moderate penetration with moderate resolution have been developed and are installed in virtually every oceanographic vessel operated by oceanographic institutions and federal agencies. These systems, also available through contracted geophysical services from several commercial firms, have been perhaps most widely used for geological and geophysical studies of continental shelf structure, stratigraphy, and mineral resources. The higher powered, deep-penetrating, low-resolution systems have been employed in studies of earth crustal structure but are most widely used by geophysical firms in search of petroleum resources. In fact, acoustic profiling systems have almost entirely replaced the offshore seismic reflection operations using dynamite that were so popular as recently as 5 years ago.

11. Excluding the simpler, lower powered, shallow-penetrating systems, the current state-of-the-art of acoustic subbottom profiling is such that nearly all systems in use were custom-made for a particular purpose or a particular operating environment. So-called general purpose systems are in use and generally are the ones commercially available; however, the wide range of utilization usually has been achieved only with a sacrifice in resolution or penetration, or both.

Inherent Limitations

12. Regardless of the energy source used, it is physically impossible to achieve both high resolution (ability to resolve closely spaced reflecting horizons) and deep penetration. As has been concisely explained,[1] the attenuation of the amplitude of an acoustic signal in a given bottom sediment is roughly a constant in terms of the wavelength of the signal. This constant is usually expressed in decibels per wavelength. Thus, if a signal with a frequency of 1 kilocycle per second (kcps) and a wavelength of 5 ft* travels through 100 ft of sediment with an attenuation of 4 decibels (db) per wavelength, it is attenuated by 20 db. If, however, the signal frequency is lowered to 100 cycles per second (cps) with a wavelength of 50 ft, the attenuation will be only 2 db. Therefore, the lower the frequency used, the deeper the penetration for a given attenuation. It would thus seem desirable to use as low a frequency as possible in subbottom profiling, but this has one serious drawback. The lower the frequency of the signal transmitted, the longer must be the length of the output pulse, and thus the poorer the ability to discriminate between adjacent strata, since no structure closer together physically than the pulse length multiplied by the velocity of the signal can be recorded.

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* A table of factors for converting British units of measurement to metric units is presented on page xi.

PART III: SOUND SOURCES

Introduction

13. As indicated in fig. 3, energy released from the combustion of

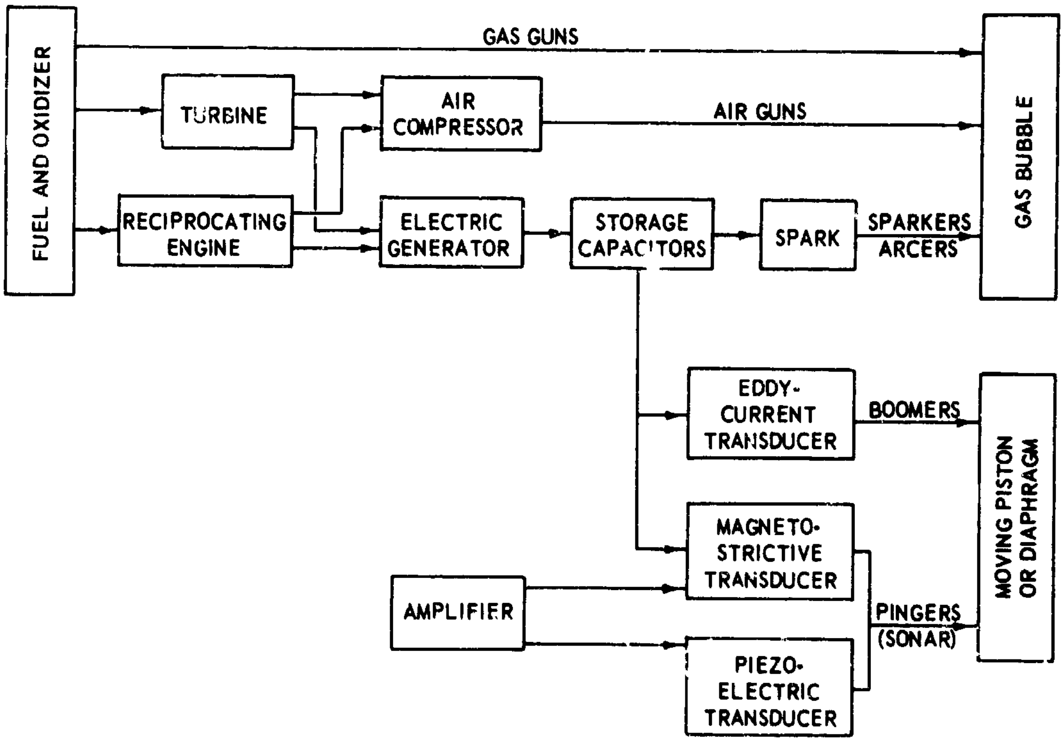

Fig. 3. Morphology of common sound sources used in subbottom profiling (modified from reference 4)

fuel is commonly converted to acoustic energy or sound in one of five basic ways for use with a subbottom profiling system. The purpose of a sound source is to produce a high-intensity, compressional wave in the water in a desired frequency band.[4] Ideally, the signal should be of short duration and must be repeatable at short intervals.

14. For the most part, the different sound sources represent more than just attempts by different manufacturers or developers to accomplish the same goal by slightly different methods. Although there is some overlap or accomplishment of similar effects, each sound source represents a

fairly discrete range of operating frequencies and, consequently, discrete resolution and penetration capabilities.

15. The order in which the sound sources are discussed represents a quasi-continuum from the standpoint of frequency and, hence, resolution and penetration. Pingers generate the highest frequencies and produce the highest resolution, but achieve the shallowest penetration; air guns and gas guns, on the other hand, generally produce the lowest frequencies and yield the poorest resolution, but achieve the deepest penetration.

Pingers

Piezoelectric transducer type

16. For all practical purposes, a piezoelectric transducer-type pinger or "sonar" system is little more than an echo sounder or fathometer that operates at a frequency of usually not over 12 kcps. The pinger probes currently available (see table 1) for subbottom profiling achieve penetration largely because of their relatively intense acoustic signal (usually over 100 db) and achieve high resolution because of their extremely short pulse length (frequently less than 1.0 msec).[7]

17. Aside from the recorder (to be discussed in Part IV of this report), the essential and unique components of a pinger system are a transceiver (or trans-driver) and either one or two submersible transducers. The transceiver contains the electronic driver circuitry (power supply, storage capacitors, and discharge and triggering circuitry) and amplifiers[8] and is either housed separately in small metal cabinets,[9] such as in the EG&G Pinger Probe (fig. 4) and the Edo Model 415 (fig. 5), or is built into the recorder, such as in the Ocean Sonics Model OSR-119T/XD-5. The transducers used with most pinger systems consist of an array of ammonium dihydrogen phosphate (ADP) crystals immersed in oil in a cylindrical- or conical-shaped aluminum housing. Some pingers like the EG&G and Edo systems use a single transducer for the transmitting and receiving functions, whereas others like the Ocean Sonics system achieve highest resolution by using a separate transducer for each function although the use of just one is possible.

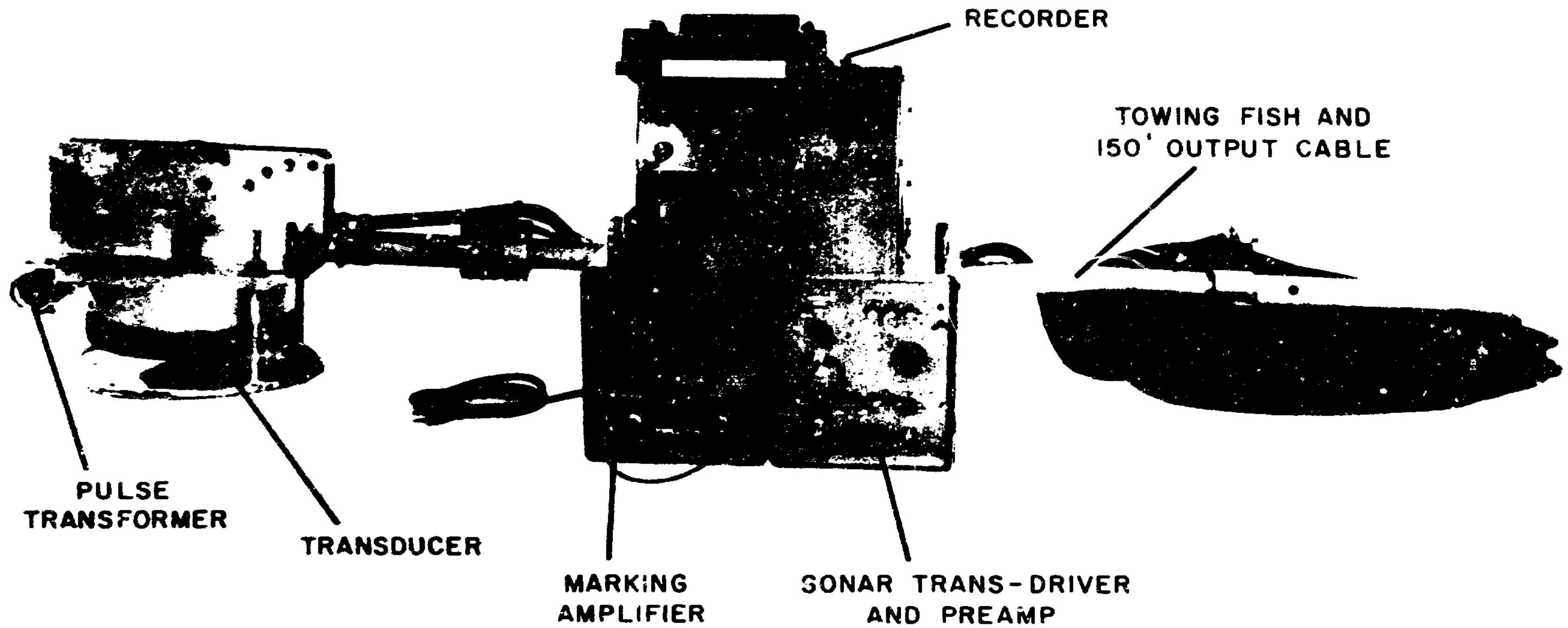

Fig. 4. EG&G International, Inc., 12-kcps pinger probe system

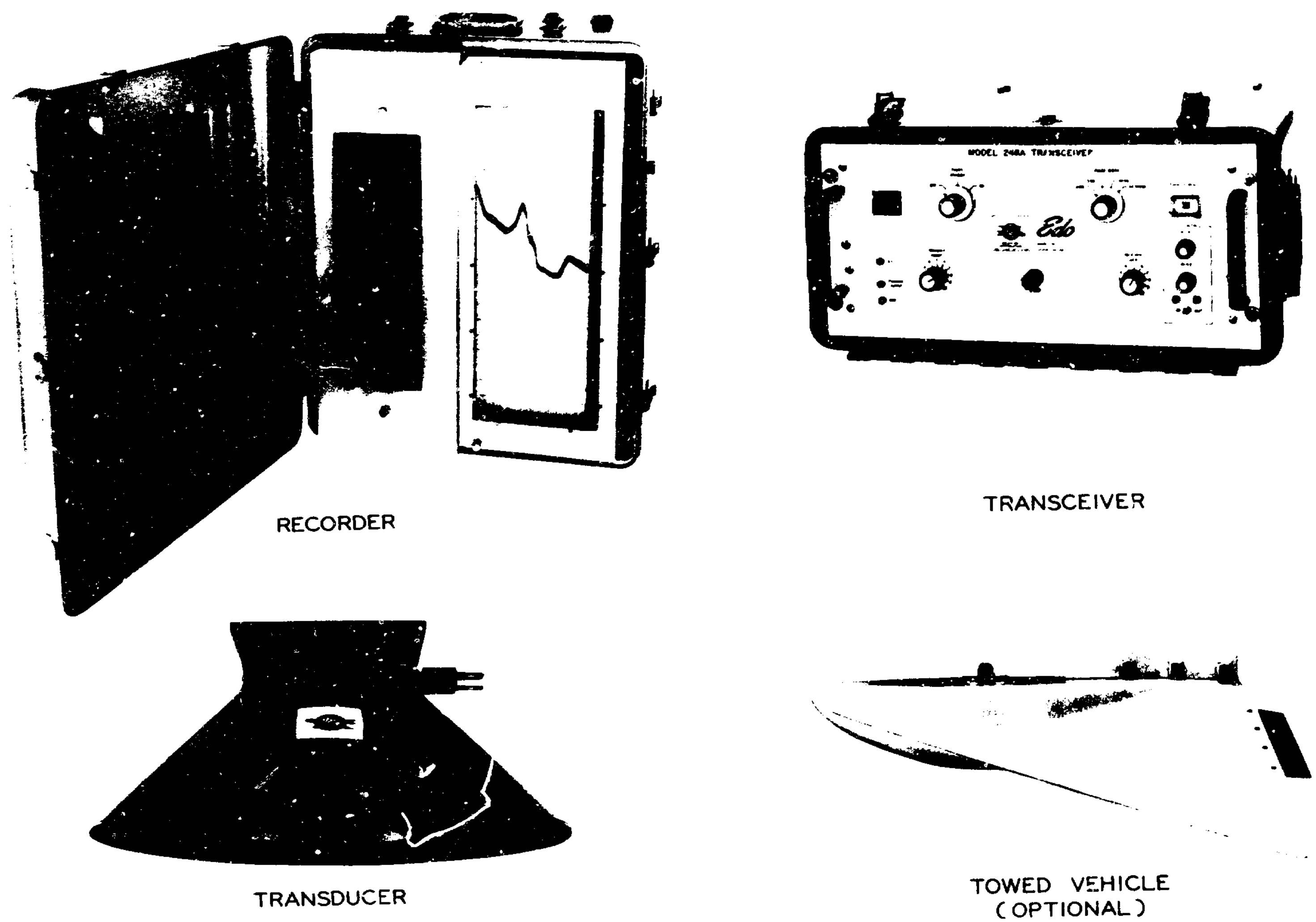

Fig. 5. Edo Western Corp. Model 415/7.0 acoustic subbottom profiling system
(components not to scale)

18. Although the operational characteristics of the pingers are essentially fixed, some systems such as the Edo system have provisions for changing the pulse length and others such as the EG&G and Ocean Sonics systems permit the selection (by simple switching) of from two to four different operating frequencies.

Magnetostrictive transducer type

19. The Sonoprobe system developed by the Magnolia Petroleum Co. and the Elac Bottom Penetration Sounder (table 1) are the only known systems that utilize magnetostriction* rather than the piezoelectric effect in the transducers to produce acoustic signals. The Elac system, manufactured in West Germany and distributed in the U. S. by Brown and Ross, Inc., is commercially available; however, only several models of the Sonoprobe were ever built, and these are now in the possession of and used only occasionally by such groups as the Scripps Institution of Oceanography (SIO) and the Southwest Research Institute (SWRI).

20. Rather than a transceiver, both the Sonoprobe[6] and the Elac systems employ a pulse generator or pulser and a separate amplifier. The Elac system uses a single transducer, but two transducers are required with the Sonoprobe. Compared with the piezoelectric-type transducer, the magnetostrictive-type transducers are large and heavy. This is particularly true in the case of the original Sonoprobe system which, partly because of its prototype nature, was somewhat crude and heavy and used vacuum-tube circuitry rather than solid-state circuitry. It is believed that some modifications, including the conversion to a piezoelectric-type receiving transducer, have been made to the Sonoprobe used by the SIO.

Boomers

21. The popular terms boomer, pulser, snapper, and thumper all have been used, sometimes synonymously, to refer to several acoustic subbottom

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* Magnetostriction involves the linear expansion and contraction of an iron rod through a gradually increasing longitudinal magnetic field, whereas the piezoelectric effect involves the expansion and contraction of a crystal through the application of an electric field.

profiling systems that utilize an electromechanical-type transducer. The best known and most widely utilized electromechanical transducer, now referred to as the boomer,[10] was developed about a decade ago by Dr. H. E. Edgerton of the Massachusetts Institute of Technology. The basic boomer, or Standard Boomer, although modified and improved several times, recently has been largely superseded by the High-Resolution Boomer, which is operated as a proprietary system by EG&G International.

22. Excluding a recorder and towed hydrophone, the basic boomer system consists of three basic components: a power supply, a capacitor bank, and a transducer.[8] The power supply converts 110- or 220-volt (v) alternating current (AC) to 3500 to 4000 v by means of a transformer. Once rectified, the current is stored in a capacitor bank which, on earlier models, held 1000 joules (J) but which was later expanded to hold 13,000 J to handle more powerful transducers.

23. The boomer transducer, an early model of which is illustrated in fig. 6, consists of a flat coil of wire which is magnetically coupled to

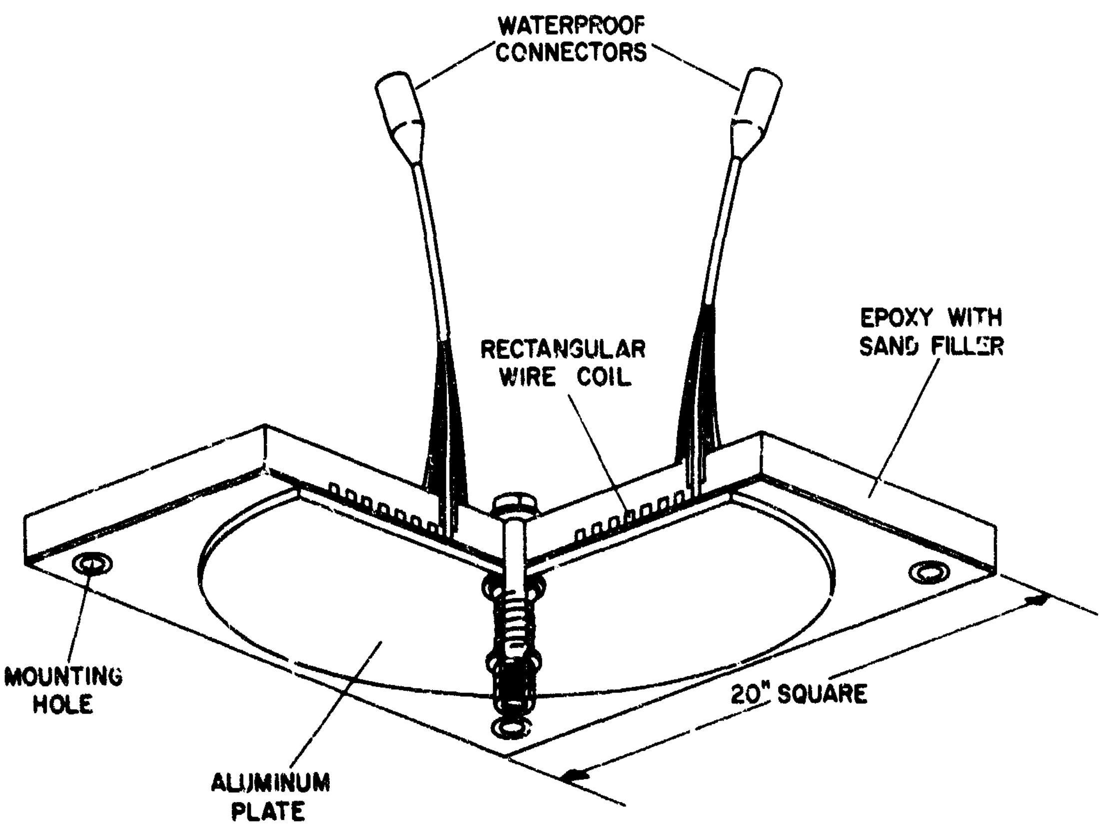

Fig. 6. EG&S Standard Boomer transducer

either one or, in later models, two spring-loaded aluminum plates.[10] When energy from the capacitor bank is discharged into the coil, induction currents are created that violently repel the plates, resulting in a sharp positive pressure or acoustic pulse. Either a spring or a rubber member forces the plates back against the coil after each repulsion. In the Standard Boomer, cavitation results behind the plates upon initial repulsion and sometimes, to a lesser extent, when the plates are returned to the coil. Since cavitation also results in an acoustic pulse, each outgoing signal therefore may consist of two or three separate pulses over a period of 10 msec or more.

24. The presence of cavitation pulses in the acoustic signal results in a long and "dirty" signal and, hence, poor resolution. This fact plus the fact that cavitation phenomena result in rapid wear and eventual destruction of the plates in the transducer were instrumental in the development of the High-Resolution Boomer. The transducer in this system operates in a manner quite similar to that of the Standard Boomer but, as a result of the addition of certain patented improvements, without cavitations.[11] Hence, it produces a clear, discrete acoustic pulse. Partly because of greater efficiency, the High-Resolution Boomer transducer is normally operated with between 200 and 500 J of stored energy rather than with several thousand or more.

25. The transducer of the Lister Bubble Pulser[12] operates on essentially the same principles as those of the boomers; however, as indicated in table 1, the dominant frequency is lower and the pulse length is considerably longer, suggesting deeper penetration but poorer resolution capabilities. However, the Lister system is considerably smaller and lighter and operates on an appreciably smaller amount of stored energy (16 J, nominal). Both EG&G boomer systems and the Lister system employ a float assembly or catamaran-type vehicle (fig. 7) for towing the transducers behind the survey boat.

Sparkers and Arcers

26. The discharge of stored electrical energy between electrodes in

Fig. 7. EG&G High-Resolution Boomer transducer mounted on float assembly

salt water to create a spark and a consequent high-intensity pressure pulse is without doubt the most widely utilized and versatile sound source for subbottom profiling. The ability to easily control the energy level of the source permits "tailoring" the frequencies in the acoustic pulse to accommodate either high resolution with shallow penetration or low to medium detail with deep penetration.[13] Dr. J. B. Hersey of the Woods Hole Oceanographic Institute (WHOI) patented the technique over 15 years ago,[14] and it was developed further at the Lamont Geological Observatory.[15] Personnel from the observatory later founded the Alpine Geophysical Associates, Inc., one of the first and still prominent firms engaged in acoustic subbottom profiling.

27. Similar to boomer systems, the basic components of a sparker or arcer system consist of a power supply (transformer and rectifier), a capacitor bank, an underwater spark transducer or electrode, plus a recorder and towed hydrophone.[16] Considerable evolution of electrode configuration has occurred in the short history of its use. The initial electrode,

closely resembling an automotive-type spark plug (hence the name "sparker"), consisted of a central anode and an encircling cathode.[15] Subsequent modifications have included the use of two closely spaced bar-type electrodes,[17] an insulated bar or cable with an outside cathode shield,[18] two parallel cables (one with a tungsten anode electrode and the other serving as a cathode or ground),[14] and most recently, the direct discharge of electricity from an electrode to a sea water ground.[19] The name "arcer" originated with the use of the latter configuration where, because of considerably higher energy levels, the electricity can arc between two separate electrodes. Whereas a single electrode was normally used with earlier sparker or arcer systems, it is now common practice to use an array consisting of multiple electrodes such as the one illustrated in fig. 8.

28. The initial high-pressure pulse produced by an underwater electrical discharge results from the formation and rapid expansion of a

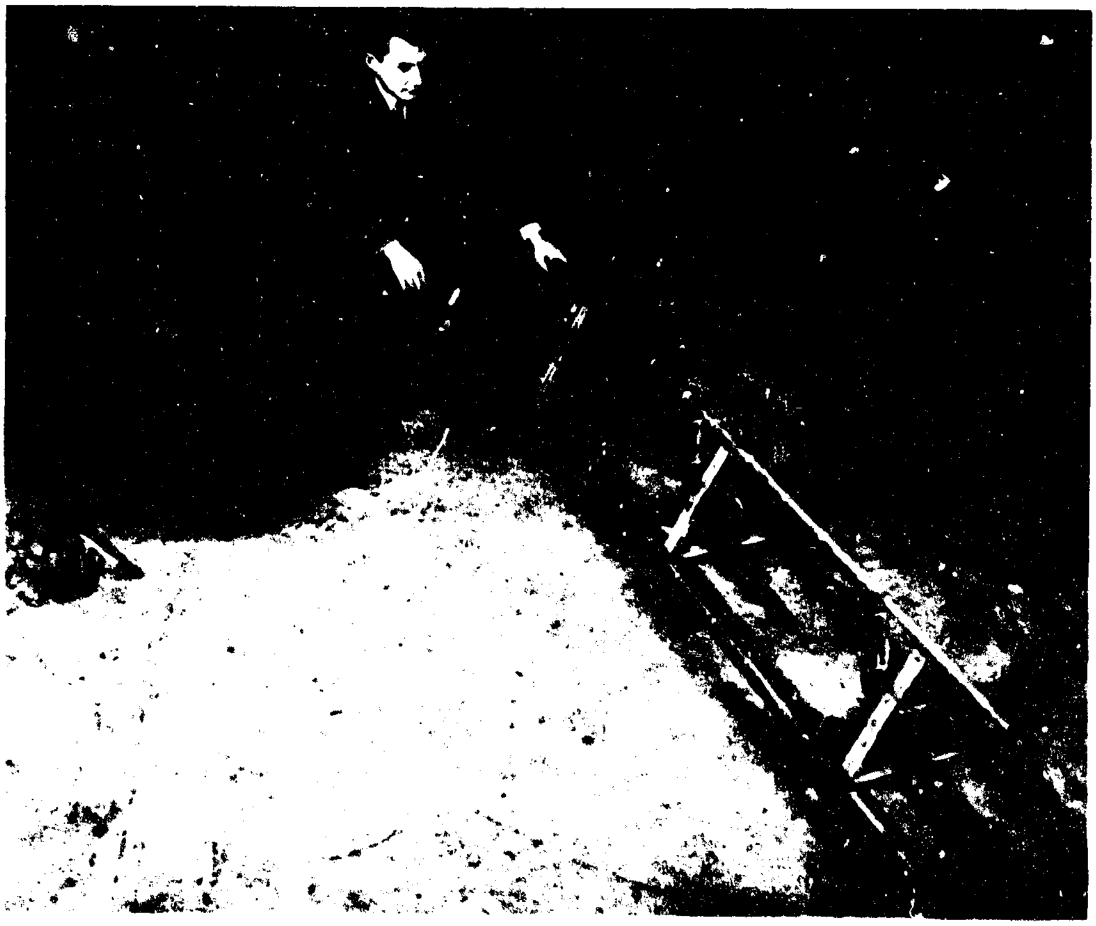

Fig. 8. EG&G International, Inc. Sparkarray electrode assembly

bubble composed of steam plus ionized gas or plasma.* As the steam cools and returns to a liquid form, the bubble collapses or "implodes", producing a second pressure pulse that is nearly an order of magnitude greater than the initial pulse.[13] Thus, the resultant acoustic signal is rather long and consists of two major pulses which, together, provide the low-frequency components necessary for deep penetration.

29. The magnitude of the initial pulse is determined by the voltage level of the capacitor bank, and the "lifetime" of the bubble is a function of several factors, including the amount of energy stored in the capacitor bank. As a consequence, it is possible, by changing the voltage and/or the amount of stored energy, to achieve widely varying results in terms of resolution and penetration. As indicated in table 1, sparker and arcer energy levels vary from as little as 50 to 100 J (the higher resolution, shallower penetration systems) to as much as 160,000 to 200,000 J (achieved through the use of multiple electrodes and for very deep penetration).

Gas Guns

30. Developed about 10 years ago by personnel of the Lamont Geological Observatory,[20] the gas gun is probably the mechanically simplest of the repeatable acoustic sound sources. The original gas gun, called the "RASS" (table 1), consists of a small (2 by 6 in.) combustion chamber into which is fed continuously a 1:5 mixture of propane and oxygen.[3] The mixture is exploded at the desired rate by energizing an electrode or spark plug. It is housed in a torpedo-shaped body or "fish" for smooth towing, with only the combustion chamber open to the water. Energy released by the gun is characterized by dominantly low frequencies (less than 100 cps) which are desired for deep penetration; however, the low frequencies and the presence of bubble pulses result in poor resolution.[1]

31. Possibly the greatest development and modifications of the gas gun sound source have been made by the Sinclair Oil & Gas Co. The Sinclair

* When considered in this regard, both sparker and arcer systems can be referred to simply as plasma systems.

Dinoseis System[21] (table 1) incorporates a bottom plate and an exhaust valve-vent system which results in a completely self-contained explosion. Since the gas is vented to the surface, there is no distortion of the signal by bubble noises. Furthermore, the bottom plate is designed to avoid the problem of cavitation. Designed for deep penetration for petroleum exploration, the Dinoseis gas guns are quite large and heavy, ranging in weight from 700 to 7000 lb.

32. In most gas gun systems, liquefied oxygen and propane are used and are stored in deck-mounted tanks. Aside from receiving and recording components, only a minimal electrical generation system is needed for the detonating energy.

Air Guns

33. Air guns generate very low-frequency acoustic energy as a result of the explosive release of high-pressure air directly into water.[22] The spectrum of the acoustic signal created by an air gun is a function of the amount of air released, the pressure of the air, and the rapidity with which it is released.[23]

34. Although each of the air guns listed in table 1 was developed separately during the last decade and differs significantly in basic design, they all involve several air chambers, pistons, and various seals and valves. The operating components of the PAR Air Gun, a proprietary product of Bolt Associates, Inc., and the most widely used air gun, are illustrated in fig. 9.

35. To achieve maximum flexibility in the "tailoring" of the output signal, Bolt Associates, Inc., has developed four PAR Air Guns that cover the range from 1 to 2000 cu in.[22] All four guns require the same electrical triggering pulse and all four operate at a maximum pressure of 2000 pounds per square inch gage (psig). The smallest gun, covering the range from 1 to 10 cu in., weighs 26 lb, and the largest gun, covering the range from 200 to 2000 cu in., weighs 875 lb. It is common practice to employ an array of guns of various sizes to produce the desired signal, and as many as 30 guns have been used in a single operation.

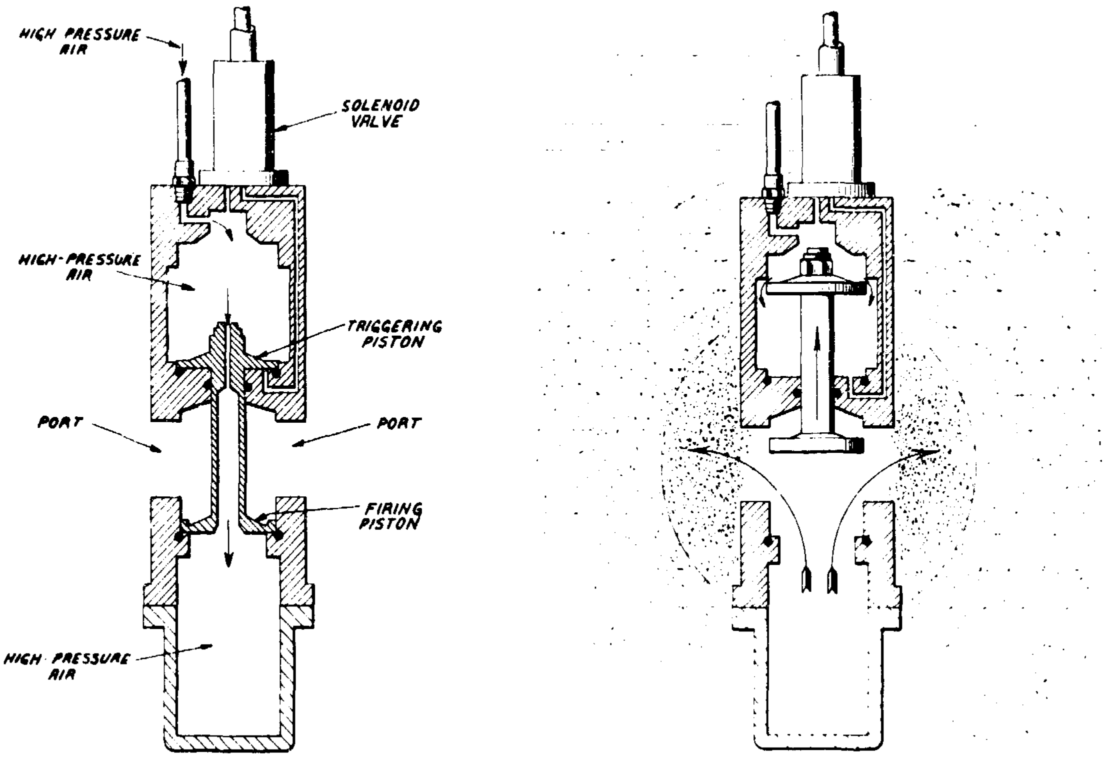

Fig. 9. Operating components of a PAR Air Gun

36. Towing assemblies of various configurations have been devised for air guns. Typically, high-pressure air is supplied to each gun from a diesel-engine-driven compressor by flexible, armored air hoses. All guns are connected to a firing control circuit and are triggered by electrical pulses generated under the control of the recording system.

Others

37. In all of the energy or sound sources discussed so far, the outgoing signals have certain inherent pulse shape or duration characteristics (i.e. the wave form) that cannot be changed. Some enhancement and/or deconvolution of the signal to achieve higher resolution therefore can be accomplished, in effect, only by filtering the returning signal before it is recorded. An alternate approach to the problem is to transmit a controlled wave form or signal, an approach attempted by the Raytheon Company with its hydroacoustic transducer.[24]

38. The system developed by Raytheon consists of a recorder and hydrophone plus a signal processor and the hydroacoustic transducer.[25] The signal processor generates a wideband signal, the precise characteristics of which are determined by a reference signal stored in memory in a replica correlation receiver. The excitation signal is then amplified and converted into a hydraulic signal and transmitted into the water by the transducer. Functional components of the transducer include a hydraulic pump, oil reservoir, servo valve, and a hydraulic ram or piston. The mechanical response of the piston faithfully follows the frequency and amplitude of the remote-control reference signal.

39. Although a long pulse length results from the hydroacoustic transducer, resolution is indicated as being moderately good.[25] The penetration is probably equal to that of a low- to medium-powered sparker but with better resolution, largely because of the absence of bubble pulse effects. The entire transducer is relatively heavy (about 2800 lb) and is normally connected by hydraulic lines to a hydraulic supply housed aboard ship.

40. In addition to the Raytheon hydroacoustic source, there are several other sound sources used in continuous subbottom profiling that do not fit into the above-mentioned classification. However, since they are relatively large and heavy systems designed for deep penetrations and used almost exclusively for petroleum exploration, they are not discussed or evaluated in this report. Included in this category is the WASSP, or exploding-wire system, of the Teledyne Corp., the Hydro-Sein system of Marine Geophysical Services Corp. (utilizing a massive implosion as the sound source), and the Vibroseis system of the Continental Oil Co. (utilizing a servo-controlled vibrator as the sound source).

PART IV: RECEIVING AND RECORDING COMPONENTS

Hydrophones

41. In the case of pinger systems, it has been found to be practical and desirable to detect acoustic signals reflecting back from subbottom horizons by a single receiving transducer which sometimes also serves as a transmitting transducer. Since the operating frequencies of pingers are significantly higher than the frequencies contained in boat "noise", it is not necessary to position the receiving transducer away from the survey boat.

42. With all other types of sound sources, however, it is essential to use a towed hydrophone. Most frequently, the hydrophone is of the line-array or streamer type, consisting of a series of pressure-sensitive detectors or elements contained in an oil-filled, neutrally buoyant, neoprene or plastic hose. A search of the literature revealed the use, by various groups, of hydrophone arrays varying in length from about 10 to 100 ft, with from 5 to 100 detectors (usually piezoelectric ceramic devices) per array; however, most appear to use an array of 10 detectors in a hose of about 12 to 25 ft in length. Typically, the detectors are connected (either in parallel or in series) and a single channel carries the generated electrical pulses to the recording components.

43. All hydrophones are designed to yield the highest possible signal-to-noise ratio with a given system and sound source. The noise factor involves "self-noise" generated by motion of the hydrophone through the water, noise of the boat's machinery transmitted into the water, vibrations transmitted down the towing cable,[4] and strumming of the towing cable itself.[24] Since most of this noise propagates horizontally, the linear (and consequently directional) nature of the hydrophone results in the sound reaching individual detectors at slightly differing times and hence is uncorrelated. Signals reflecting from subbottom horizons move vertically upward and usually reach all of the detectors simultaneously; hence, they are correlated and result in the generation of a stronger electrical pulse than does the noise.

44. As would be expected, the larger and more elaborate hydrophones are needed and are used with the lower frequency, more deeply penetrating systems in which the reflecting signals frequently are much weaker. In the design of most hydrophones, the number of detectors and the total length of the array are determined by the signal frequency band.[24] The total length should be greater than the wavelength corresponding to the lowest signal frequency that is to be recorded. The maximum spacing between detectors should be less than one-half the wavelength corresponding to the highest signal frequency to be recorded.

45. Dozens of domestic firms manufacture hydrophone components, and several fabricate arrays to customers' requirements; however, most arrays are custom built by the various operators of acoustic profiling equipment.

Recorders

Analog recorders

46. All analog or graphic recorders in use with acoustic profiling systems are modifications of facsimile recorders using electrosensitive paper.[4] They are normally classified as either helix or stylus types and use either wet (actually only damp) or dry paper.

47. Wet-paper helix recorders, first developed by the WHOI and called precision graphic recorders or PGR,[8] are probably most frequently used: popular brands include the Alden, Alpine, Bludworth, and Muirhead recorders. In these recorders, an electrical signal passes from a negative helix through the damp, chemically treated paper to a positive fixed or slowly moving electrode. Ferrous ions are deposited on the paper in shades of intensity (sepia colored) that depend on the strength of the electrical signal. Figures 10 and 11 illustrate two types of wet-paper recorders in widespread use.

48. Dry-paper stylus recorders, first developed at the Lamont Geological Observatory and called precision depth recorders or PDR, operate by means of an electrical signal on a moving electrode that burns off a thin layer of the recording paper to expose a black underlying layer. The Westrex recorder and Edo Corporation's Precision Bathymetric Recorder (see fig. 5)

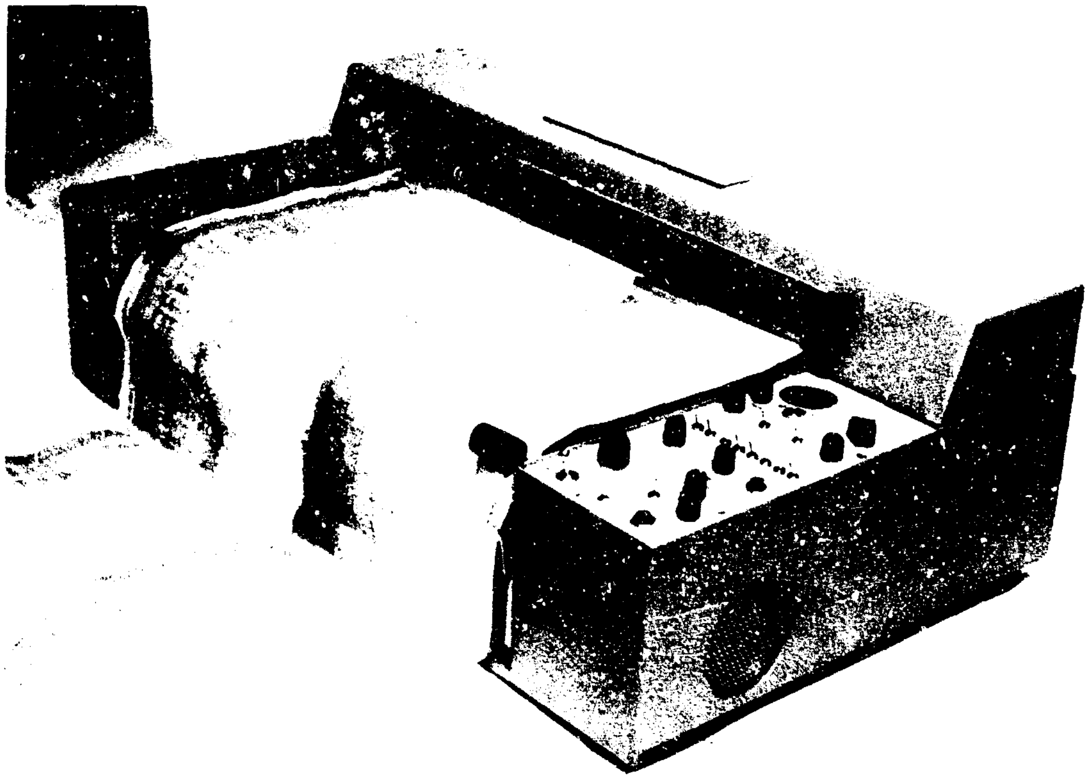

Fig. 10. Gifft recorder (now manufactured by Hydro Products) as used with Ocean Sonics, Inc., and Ocean Research Equipment, Inc., pinger systems

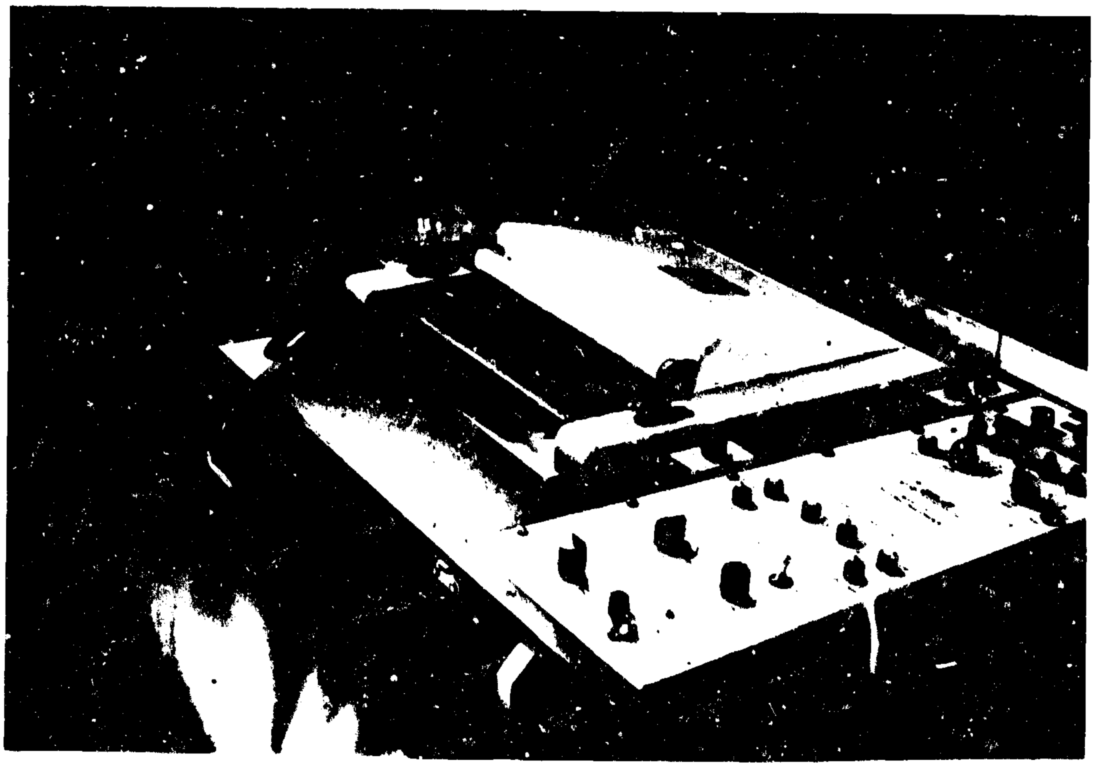

Fig. 11. Recorder used with EG&G High-Resolution Boomer system

are examples of this type. In general, dry-paper records are more durable, easier to work with, and less subject to wrinkling than wet-paper records; however, helix-type recorders are generally more accurate and more dependable than stylus-type recorders.

49. Some recorders of both types use paper with widths of only 8 or 9 in.; however, widths of 11.5 in. and 19 in. are probably most common. All recorders offer a choice of various sweep speeds that enables the user to select the vertical scale most suited to the water depth and depth of bottom penetration encountered. Recorders used with deeply penetrating systems may provide several sweep speeds between 0.25 and 5.0 sec (or 0-600 and 0-12,000 ft)* for example, while those used with shallower penetrating systems may provide selectable sweep speeds between 0.05 and 1.0 sec (0-120 and 0-2,400 ft).

50. Both Alden and Alpine, and possibly other firms, manufacture dual-channel or multiple-channel recorders.[2] These permit the simultaneous recording of either two separate sound sources (such as a 50- and a 200-J sparker fired alternately, as does Alpine) or differential filtering of a single source to record the lower frequencies on one channel and the higher frequencies on the other. This produces two adjacent records with the same horizontal and vertical scales that might contain substantially different data in regard to resolution and penetration.

Signal processing

51. After a reflecting signal has been detected by a transducer or hydrophone, it must be amplified and filtered before it can be recorded. Pre-amplifiers or simple linear amplifiers are often incorporated in the hydrophone itself as an initial amplification technique. The usual next step is to pass the signal through an active variable band-pass filter to exclude undesirable frequencies. Final amplification is accomplished by one of several types of gain control incorporated in the recorder.

52. Simple linear amplification is usually undesirable since it results in overloading of the recorder and sometimes burning of the record

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* Calculated using an assumed sound velocity in water of 4,800 feet per second (fps).

by early arriving strong signals and no recording of later arriving weak signals.[4] A simple manually adjustable gain control can be used to amplify signals from a certain subbottom horizon at the expense of other signals; however, it is only slightly more complex to incorporate into a recorder a time-variable gain (TVG) that raises the amplification of the system at some arbitrary function of time after either the initial impulse or the water-bottom reflection. It is also possible to use an automatic gain control (AGC), but this results in the loss of all information about the relative strength of signals from different horizons. A delayed automatic gain control (DAGC), which reduces amplification at a fixed time after the beginning of a strong signal, does, however, preserve some amplitude information.

Other recording techniques

53. It is now almost universal practice on the part of geophysical and petroleum companies conducting petroleum exploration surveys with deeply penetrating sound sources to record all returning signals on magnetic tape. This can be accomplished with or without the simultaneous use of an analog recorder. Magnetic-tape recording is also being employed on an ever-increasing scale by the various operators of sparker or arcer systems. The value of tape recording lies in its ability to record the entire return signal spectrum without first having to remove mostly undesirable but sometimes useful frequencies that would clutter an analog recording. Data on tape can be processed or digitally converted for later playback, with selective filtering and "experimentation" taking place at that time. Thus, it is frequently possible to ultimately extract a greater amount of information in the areas of weak signals or high background noise through this recording technique. Most operators of pinger and boomer systems feel that the types of surveys that are conducted with these sound sources do not warrant the appreciable expenditures necessary for tape recording facilities.

PART V: PERFORMANCE CHARACTERISTICS

Resolution and Penetration

54. As indicated earlier, it is not possible to achieve both high resolution and deep penetration regardless of the sound source used. Both parameters are influenced by the wavelength (a function of frequency), pulse length, and pulse configuration of the outgoing acoustic signal. Except for several exceptions to be discussed later, the subbottom materials play a passive role in this regard. Nearly all acoustic surveys are conducted in areas of saturated, fine- to medium-grained, unconsolidated to weakly consolidated sediments of marine, estuarine, deltaic, and/or lacustrine origin.

55. Pinger systems are usually capable of resolving individual layers less than 3 ft apart and sometimes less than 1 ft apart, but the total depth of penetration is rarely greater than 100 ft. Examples of records obtained with two different pinger systems are shown in plates 1 and 2. The High-Resolution Boomer system of EG&G International, Inc., operating with lower frequencies and longer pulse lengths, can achieve resolution of less than 5 ft with penetrations of 200 ft and occasionally more. Plates 3 and 4 illustrate the types of records obtained with this system. In contrast, the Standard Boomer, although able to penetrate to depths possibly as great as 1000 ft, yields much poorer resolution. As indicated in plate 5, a single reflecting horizon appears as a series of parallel lines on the record as a result of the cavitation pulses in the signal. The effect of the multiple lines is to decrease the resolution to 10 ft or more.

56. Multiple-line rendering of a single reflecting horizon is most pronounced with sparker and arcer systems because of bubble pulse effects (plate 6). The result of this is limitation of resolution to not less than 5 ft even with the lower powered systems. Plate 7 is an example of a moderately high-resolution, 1500-J arcer system record in which it can be seen that resolution is limited to at least 15 ft. However, effective penetration is probably about 1000 ft. For comparison, the arcer record shown in plate 8 was obtained with a 160,000-J system and indicates maximum resolution of about 100 ft. The effective penetration in this case is more than 5000 ft.

Considerable enhancement of sparker or arcer records is possible through deconvolution or removal of bubble pulse effects by computer data processing; however, this is normally done only by the larger geophysical firms.

57. Air gun and gas gun systems achieve resolution and penetration comparable to those achieved by the higher powered arcer systems. Single reflecting horizons are not characterized on the records by multiple lines; however, resolution is still relatively poor because of the long pulse lengths. An example of a record obtained with a relatively high-resolution air gun system is shown in plate 9.

Record Characteristics and Interpretation

Accuracy

58. Even at very high sweep speeds, the average analog recorder is quite accurate (usually to less than 0.1 percent of full scale) and able to record far more than can be detected. However, appreciable variations can occur in both the horizontal and vertical scales, and corrections usually must be made.

59. The horizontal scale of any acoustic subbottom profiler record is dependent upon the chart paper feed rate (a constant for any sweep speed) and the speed of the boat. Since the latter is variable because of currents, wind, etc., it is advisable to mark the record with an event mark corresponding to a known point as frequently as possible. Time-dependent event marking is available on many recorders but is less accurate over long distances.

60. Almost all recorders automatically provide horizontally ruled depth scale lines at a fixed interval. This interval is normally based on the average speed of sound in water, i.e. 4800 fps. Since the vertical scale of the record is actually one-way travel time, a time of 1 sec is roughly equal to 2400 ft, for example. Below the water bottom in the sedimentary column, this sound velocity can be used with reasonable accuracy for thin sequences; however, in thick sequences, it should be abandoned in favor of a value representing the average sound velocity of the sediments (often 7000 fps or more). The latter is admittedly complex but can be

determined by seismic refraction profiles, wide-angle reflection profiles, or test borings.[20]

61. A further source of error is present in depth determinations as a result of the fact that the indicated depth of a reflecting horizon can be as much as one-half wavelength greater than its true depth.[26] Obviously, this becomes a significant problem with the low-frequency, long-wavelength sound sources. To further complicate the matter, the use of gain control can have the effect of reducing the apparent depth of a reflecting horizon. Since it is not possible to correct for either effect, one must simply be alert to a possible source of error of a particular magnitude.

Multiple reflections

62. A problem common to all continuous recording profiling systems is recognition of multiples.[27] Multiples occur when sound energy reflects from the water bottom, travels back to the air-water interface, and is reflected downward a second time. When sufficient energy is involved and sediment conditions are conducive, as many as four or five or even more round trips can occur.

63. Interpretation can become complex when multiple reflections are mixed with reflections from subbottom horizons. However, they can generally be identified and separated from subbottom reflections by recognizing that the first multiple appears on the record at twice the depth and twice the slope of the water bottom. Each succeeding multiple is displaced downward a distance equal to the depth of the water. Plate 10 is an example of a High-Resolution Boomer record showing three multiple reflections. Most major geophysical companies have computer programs which permit them to remove multiples; however, this is seldom economically justified for purposes other than petroleum exploration.

Effects of Environment

64. It should constantly be kept in mind that various subbottom horizons produce or do not produce acoustic reflections because of relative differences in acoustic impedance. Impedance is primarily a function of density and it may or may not have a direct relationship with lithology. In other

words, a contact between materials of different lithology such as sand and clay might not produce a reflection, whereas a contact between a zone of dense sand and a thicker layer of looser sand might produce a strong reflection. Many possible combinations of conditions such as this can occur in most sedimentary sequences.

65. Although no acoustic subbottom profiling survey should be performed without "absolute" subbottom control in the form of borings, it is not surprising to occasionally find an apparent major lack of agreement between the two because of the above-mentioned occurrences. Certain features such as the top of bedrock or erosional surfaces on weathered formations normally will be quite apparent in both; however, it is not uncommon for bedding visible in cores to be invisible on the acoustic records and, conversely, for detailed bedding indicated on acoustic records to be indiscernible in cores or boring logs. The latter situation is by far the more common, and therein lies one of the primary advantages of acoustic profiling. It is often possible to discern and follow bedding and/or geologic structure in cases where it is impossible to correlate between even closely spaced borings because of a lack of visible marker horizons.

66. Much research has been conducted in an effort to perfect a method of classifying bottom or subbottom sediments according to some measurable characteristic of its reflected acoustic signal; however, results have been disappointing.[28] Many variables such as constancy of output energy are involved, and differences in the character of reflections among widely varying materials are subtle.

67. Experience with acoustic reflection profiling systems has indicated a few cases in which the lithology of a reflecting horizon can be inferred with reasonable accuracy. When pinger systems are involved, concentrations of calcareous materials such as shell reefs or coral banks produce very strong reflections and, because of this, no acoustic energy remains to reflect from deeper horizons. This produces a characteristic "signature" such as those shown in plates 2 and 11. Plate 11 also illustrates how the appearance of the reflections or signature changes when a different sound source (with lower frequencies) is used.

68. With considerable experience in a given area and a "feel" for

local conditions, it is sometimes possible to infer sediment types in other ways. For example, with high-frequency systems, it is usually possible to differentiate areas of soft clays and silts from areas of dense sands at the immediate water bottom. The latter materials allow much shallower penetration and usually result in a series of multiples. However, these are not absolute criteria because the presence of air bubbles or gas bubbles (due to aeration, bacterial action, or decaying organic matter) can have essentially the same effects.[29]

69. In general, interpretation of acoustic profiling system records is dependent upon identifying morphology and geologic structure rather than lithology. Such features as angular unconformities, erosional surfaces, lenticularity and cross-bedding, original dip structures, faults, folds, and domes are used for interpretive purposes.[27]

PART VI: OPERATIONAL CONSIDERATIONS

Vessel Requirements

70. It has been stated that effective acoustic profiling systems can be mounted in almost any craft except possibly a canoe:[2] this may be technically correct for the smaller pinger systems, but it is far from being practical. As far as weight of equipment alone is concerned, the pinger systems, exclusive of power-generating equipment, involve a total weight of at least 150 lb and frequently more. The boomer systems and smaller sparker or arcer systems involve equipment weights of several hundred pounds, and the more powerful arcers and air and gas gun systems involve weights of thousands of pounds. Considering that most surveys involve several persons (a boat operator, acoustic system operator and possibly an assistant, and usually at least one observer) and that at least minimal weather protection must be provided and seaworthiness assured, it is seldom practical to conduct a survey of any type in a boat less than 20 to 25 ft in length. Motor launches, small cabin cruisers, workboats, and sometimes small barges usually meet minimum requirements for pinger, boomer, and small sparker or arcer system surveys provided they are not excessively noisy or prone to vibrations. Most of the higher powered systems are either permanently mounted or are built in the form of modular units for installation aboard ocean-going vessels of 100-ft length or greater. For shallow-water operations, large barges have been used in numerous instances.

71. Most pinger systems require only 115-v, 60-cps electrical energy of less than 500 watts (w). Energy requirements increase to only several kilowatts for the boomer systems but rise abruptly to much higher levels for the sparkers and arcers. In almost all known cases of operation, the power source is a system separate from the vessel's power system since the latter is seldom able to meet the demands of the acoustic sound source. Although air guns and gas guns require very little electrical energy, large-capacity and usually quite heavy compressors are needed for air guns, while heavy and bulky liquid oxygen and propane cylinders are needed with gas guns.

72. The speed at which surveys can be performed depends, of course,

upon vessel capabilities, weather conditions, and similar considerations, but the towing characteristics of acoustic system components are frequently the primary determining factors. Sparker and arcer systems, employing streamlined electrode assemblies and transducers, usually permit the highest operating speeds (10 knots or more). In systems in which a towed vehicle or "fish" is used to house the transducers (see figs. 5 and 12), speeds of

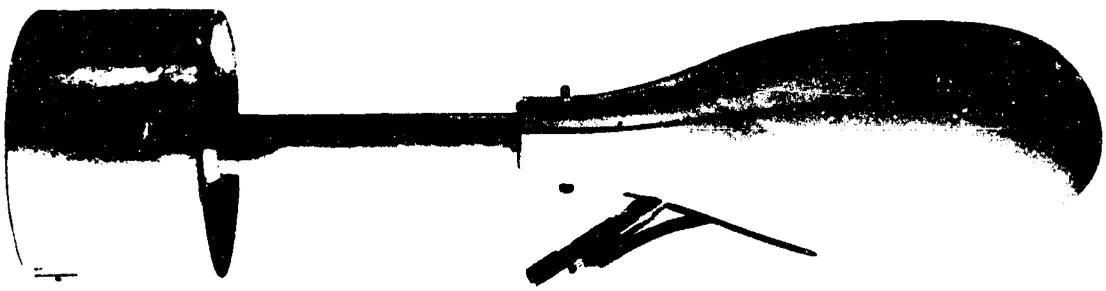


Fig. 12. Ocean Research Equipment, Inc., towed transducer vehicle

up to 20 knots have been achieved. Speeds this high are unusual, however, and are normally not attempted because of the decrease in horizontal resolution that results.

73. Operations in shallow water present certain special problems regarding transducers. The use of towed vehicles is impractical if not impossible in water less than 5 ft deep, particularly at low speeds (when steep towing angles result). "Over-the-side" mounting of pinger system transducers by means of a rigid but adjustable frame or rack fastened to the boat is commonly used for shallow-water operations. This arrangement allows operating speeds of 3 to 5 knots, but care must be taken to ensure against turbulence near the transducers which might result in formation of air bubbles and a consequent drastic attenuation of outgoing signals. The transducers of certain of the lower frequency pinger systems such as the Edo Model 415, 3.5-kcps system are relatively large and heavy (33 in. in diameter and 45 lb); consequently, a boat of substantial size is needed to support them in over-the-side mounts.

Environmental Factors

74. All sound sources discussed in this report will operate equally well in either fresh water or saline water except sparkers and arcers. These systems must have water with a salt concentration of at least 15 parts per thousand (ppt) in contact with the electrode in order for a spark or arc to form. Several organizations have adapted lower powered sparkers for use in fresh or brackish water by enclosing the electrode assembly in a flexible polyethylene bag filled with a saline solution. This technique has proven to be generally undesirable from the operational standpoint because of the poor towing characteristics of the assembly and its fragility. A slightly differing approach to the problem, such as the use of a streamlined, torpedo-shaped, semirigid housing of polyvinyl chloride (PVC) filled with a circulating saline solution, has been shown to be more effective; however, no operational units are known to be available commercially.

75. Some problems associated with operating acoustic profiling systems in shallow water have already been mentioned. In addition, shallow-water depths can have the effect of producing numerous multiple reflections and sometimes also can present problems associated with transducer ringing. This phenomenon, which is a reverberation following each ping, or signal, is usually damped out in deeper water. In shallow water, it can cause considerable noise, loss of resolution, and ghost echos. Systems that use separate transmitting and receiving transducers largely avoid this problem, and single-transducer systems under development by several companies will incorporate ringing damping devices.

76. Side echos occasionally can be a serious problem when operating acoustic profiling systems in narrow streams or close to steep underwater banks. Excluding pingers, all major sound sources are basically omnidirectional: pinger transducers do concentrate the outgoing signals; however, beam widths seldom are narrower than 30 deg. Consequently, if a sound source is positioned closer to a bank or side slope than to the water bottom, the first reflections recorded will be from the bank or slope, and these will be mixed and possibly confused with reflections from horizons below the bottom. An experienced interpreter often can determine that side echos are being recorded because of characteristic cone-shaped signatures.

PART VII: CAPABILITIES AND APPLICATIONS

Coastal Area

Pleistocene deposits

77. Excluding petroleum exploration, probably the most widespread and successful application of acoustic subbottom profiling in the Gulf Coast area has been in delineating the top of the uppermost Pleistocene formation. The top of the Pleistocene deposits is a relatively dense weathered horizon that is separated from the overlying Recent deposits by an erosional unconformity; hence, it is normally a strong reflecting horizon.

78. Some of the earliest applications of the Sonoprobe system took place in Galveston Bay and Corpus Christi Bay, Texas, and on the shallow continental shelf areas of Texas and Louisiana where the Pleistocene deposits were detected and faults, folds, and domes in them were delineated in detail to depths of 50 to 60 ft.[6] The same system was employed later with considerable success in delineating buried valleys or entrenchments in the Pleistocene deposits in other Texas coastal bays[30] and in Breton, Chandeleur, and Mississippi Sounds.[31] During the conduct of this state-of-the-art survey of acoustic systems, the writer talked with representatives of several firms that cumulatively had acquired thousands of miles of acoustic profiler records in various bays of the Gulf Coast. These records, obtained for purposes such as pipeline surveys, clam or reef shell resource surveys, and foundation investigations, indicated penetration to the Pleistocene deposits was achieved in possibly half of the total distance surveyed.

79. The acoustic characteristics of the Recent sediments of the coastal area are normally such that even the high-frequency pinger systems can penetrate through 20 to 40 ft or more of the sediments and obtain reflections from the Pleistocene deposits. Plates 2 and 11 indicate the penetration and resolution capabilities of 12-kcps pinger systems in Corpus Christi Bay. Plate 12 was prepared to show comparative penetration capabilities of the Elac 18-kcps pinger system and the Edo 3.5-kcps system under similar conditions (but not in exactly the same area) where Pleistocene deposits are exposed at the bottom or are veneered by only a thin layer of

Recent sediments. Plate 13 illustrates the resolution and penetration achieved with an EG&G 12-kcps pinger probe in the eastern end of Lake Pontchartrain. This system, operated by the NOD,[32] was able to detect the top of the Pleistocene deposits through as much as 25 ft of Recent sediments where they consisted of interbedded clays and silts; however, where the Recent sediments consisted of sands, penetration was generally less than 10 ft, and the top of the Pleistocene could not be detected except at widely scattered locations.

80. Sparker systems producing relatively high-frequency energy have been used with considerable success in mapping the top of the Pleistocene deposits in Corpus Christi Bay (plate 11) and in Matagorda and Galveston Bays[33] to depths as great as 80 ft below the bottom. Systems of medium- to high-power output lack resolution capabilities sufficient to delineate the top of Pleistocene deposits; however, major stratification within the deposits can be detected for studies of structural relationships.

<u>Ship channel surveys</u>

81. The value that can be derived from supplementing a boring program for new ship channel construction or existing channel enlargement with a high-resolution acoustic profiling survey has been demonstrated on several occasions.[2,11,33] Not only is it often possible to significantly reduce the scope of the drilling program, it is normally possible to correlate horizons between borings by other than a "straight-line" method and to detect unpredictable occasional occurrences of features such as buried reefs, bedrock pinnacles, and filled channels that could be missed in even a detailed drilling program.

82. Acoustic systems that have been used successfully in surveys of this type include pingers, boomers, and relatively low-powered sparkers or arcers. Since penetration of more than several tens of feet is not needed, selection of a system can be made primarily in terms of resolution capabilities and frequency and power output in relation to the anticipated sediment types. For example, a boomer system would be preferable to a pinger system where coarse-grained sediments such as sands or gravels are suspected or known to be present. A sparker system might prove to be more effective if the water were sufficiently saline and penetration of over 50 ft were required.

Construction materials surveys

83. Both the U. S. Geological Survey (USGS) and the U. S. Army Coastal Engineering Research Center (CERC) have extensively utilized acoustic profiling systems in surveys of mineral resources and construction materials on the U. S. continental shelves. In the Sand Inventory Programs of CERC on the Atlantic continental shelf between Maine and Florida, sparker and air gun systems have been used successfully. The greatest amount of useful information has been obtained by operating two sound sources and using dual-channel recording. In areas where the bottom sediments can be penetrated by the higher frequency sound, penetration with high resolution has been achieved to the desired depth of about 25 ft. Rather than obtaining no subbottom information where the sediments cannot be penetrated by the higher frequency sound, the simultaneous recording of lower frequency sound with the dual-channel system has resulted in obtaining some information in these areas to the desired depth but with a moderate decrease in resolution.

84. Pinger systems should not be overlooked for application in construction materials surveys. The fact that the high-frequency sound cannot penetrate coarse-grained materials and reef deposits and consequently produces a characteristic strong reflection or signature can be of considerable value in such surveys. Their use would permit the location of the upper surfaces of such deposits but would not permit determinations of deposit thicknesses. However, once a source is located by an acoustic survey, its origin usually can be inferred from its surface morphology (e.g. relict beach, reef, channel fill). Probable thicknesses of deposits then can be inferred from a general knowledge of local geologic history.

Alluvial Valley Area

Bedrock surveys

85. Acoustic subbottom profiling systems have been used with considerable success in bedrock surveys along several of the larger rivers in the Lower Mississippi Valley area.[34,35] Systems that have been used include the EG&G High-Resolution Boomer, sparkers, and gas guns. The purpose of the surveys was to evaluate the proximity of bedrock to the channel bottom and

to locate faults in connection with site selection and site evaluation studies for major structures.

86. Since virtually all major rivers in the Lower Mississippi Valley area are underlain by coarse-grained alluvial sediments (sands and gravels), pinger systems cannot be used for bedrock surveys. Boomer systems probably cannot be effective where the alluvium is greater than 50 or 60 ft thick. Sparker or arcer systems have been used successfully; however, operation of a plasma system in fresh water is difficult and could be precluded by a number of environmental conditions such as strong currents or floating ice. Although gas gun systems have also been used successfully, they afford the relatively lowest resolution and may be undesirable in inland use near populated areas because of safety factors associated with liquid oxygen and propane.

87. It is believed that air gun systems could be used quite effectively and possibly even most effectively for bedrock surveys in large rivers. These systems afford the user considerable latitude in "designing" a power output and frequency spectrum to achieve maximum resolution and penetration. A wide range of gun assemblies is possible depending upon the number of guns used, the sizes of the guns, and the operating air pressure. All air gun systems can be operated at power output levels and frequencies that would permit penetrations through several hundred feet of coarse-grained alluvium.

Site evaluations

88. The writer is not aware of cases in the Lower Mississippi Valley area where acoustic systems have been used for detailed investigations of specific sites for structures such as locks and dams. However, the benefits that could result from surveys of this type might be substantial, particularly if bedrock faults are suspected or known to be present. Even under ideal conditions, accurate mapping of faults located beneath a stream and/or alluvium is time-consuming and requires closely spaced and detailed subsurface control. On the other hand, there is probably no type of geologic structure that can be delineated more readily and more accurately by acoustic profiling systems than a fault, provided that some reflections can be obtained from bedding planes or similar features. This is normally

possible in most types of carbonate or clastic sedimentary rocks.

89. All factors considered, boomers and air guns would appear to offer the best possibilities for surveys of this type. Some operational problems could be associated with running cross sections or transverse survey lines with conventional craft on narrow streams; however, other procedures such as the use of small barges or floats and bank-anchored cables could be utilized. Problems associated with conducting a survey in a narrow channel could possibly be minimized by scheduling the survey for periods of bankfull discharge or even overbank flooding provided that other factors such as current velocity are not adverse. In either case, it might be advantageous to devise special transducer and/or hydrophone configurations particularly suited to local conditions.

Reservoirs

90. Although probably too few tests have been made to indicate conclusively, preliminary indications are that artificial bodies of water present special problems regarding acoustic subbottom profiling. As experienced in a reservoir in Georgia,[29] penetration of only several tens of feet of alluvium by a boomer sound source was found to be essentially impossible even after considerable experimentation. The indicated reason for this failure was the presence of countless small air bubbles remaining entrapped in the aerated or weathered zone of the floodplain after submergence brought about by reservoir filling. It was concluded that the reservoir is not old enough (about 8 years old) for the air to have become dispersed nor deep enough (about 40 ft) for the air to have become compressed sufficiently to negate its attenuation effects. Although probably not present at this site, gas bubbles resulting from the decay of organic matter in an old soil horizon would have had a similar deleterious effect.

91. There are no known cases that would help in estimating how old or how deep a reservoir must be to negate the effects of air or gas bubbles. In all probability, a simple answer to this is not possible since there are probably other factors involved such as quantity of air or gas and the frequency of the sound energy used in the survey.

92. It is known, however, that considerable success has been achieved in reservoirs in delineating the thickness and extent of sediments deposited subsequent to reservoir filling. These normally contain no air or gas bubbles, are considerably less dense than prereservoir deposits, and can be penetrated to depths of several tens of feet by even the higher sound frequencies (i.e. 12 kcps).[5] Since both the water bottom and the base of the sediments (a strong reflector because of reasons just mentioned) can be delineated with accuracies of about 1 ft or less with pinger probes, it is not necessary to conduct annual or periodic fathometer surveys and prepare comparative profiles in studies of reservoir sedimentation. At any given time, a pinger probe survey could be made to determine the water depth and the total amount of sediment accumulated to that time without profile comparison.

Adaptation for Land Use

93. Although acoustic profiling systems are currently exclusively waterborne because of the inherent necessity of introducing the sound pulses directly into water, attempts have been made to ground-couple transducers for overland surveys. Research directed toward this goal, promoted in large measure by an urgent need for an effective method of locating Viet Cong tunnels, has involved investigations of such techniques as (a) suspension of transducers in fluid-filled rubber or polyethylene bags placed in contact with the ground, (b) introduction of acoustic energy into the ground by means of spiked rollers or wheels, and (c) pouring water on the ground surface or rapidly excavating and filling shallow trenches with water to permit the use of conventional transducers. All known attempts of this type have been unsuccessful in regard to the higher frequency systems, largely because of an inability to completely saturate the ground and disperse trapped air above the water table. It is possible to propagate low-frequency sound effectively under these conditions; however, this type of sound lacks the desired resolution capabilities.

94. Similar problems would probably be encountered in most, if not all, cases of attempted utilization in marsh or swamp areas. Transducers

of the smaller systems such as pingers and boomers could be mounted on a sled or skid-type platform for towing behind a marsh buggy, air boat, or similar vehicle capable of negotiating extremely shallow water. However, since nearly all such areas experience seasonal drying and contain decaying organic matter, air and/or gas will usually be present in the upper few feet of sediment and will preclude the effective use of high-frequency acoustic systems.

PART VIII: SYSTEM SELECTION

95. The present state-of-the-art of acoustic subbottom profiling is such that it is inadvisable, if not impossible, to recommend the use of a specific system for a particular problem or location. Considering only certain obvious factors such as the frequency of the sound energy or the power output, there are usually several different systems that would appear to be applicable; however, the final selection of a system must be based on a consideration of numerous less obvious factors. Even then, there can be only a limited amount of confidence as to whether satisfactory results will be obtained. Unfortunately, an actual field test is almost always the only way to ascertain performance capabilities.

96. Theoretical capabilities of systems are known or can be determined from the mechanical or electronic design of the system. On the other hand, it is seldom possible to determine the acoustic characteristics (i.e. velocities, magnitude of impedance of reflectors) of the sediment and/or rock to be penetrated. Therefore, only operational considerations remain as factors to be evaluated in system selection. Included in this are factors such as size and weight of components, necessity for towed transducer vehicles, power generation requirements, type and operational characteristics of recorder, and hydrophone configuration. Information of this type is normally not contained in manufacturers' brochures or promotional literature; however, most, if not all, manufacturers can provide technical data sheets and system specifications.

97. In the opinion of the writer, acoustic systems are not sufficiently well developed or versatile to warrant development or purchase by a CE district office for geologic investigational use. This opinion has been derived from an awareness of the variety of projects (and geologic settings) in which systems could be used, the relatively short period of time necessary to conduct any given survey, and the relatively low rate of recurrence of projects of a particular type or in a particular environment. A possible exception to this might be a situation in which a relatively low-cost system such as a pinger probe could be acquired for a number of similar projects such as reservoir sedimentation surveys.

98. Insofar as is known, all major systems can be either leased or can be obtained by means of contracted geophysical survey services. Leasing is recommended as being most economic for the smaller and simpler systems (pingers or boomers) provided that technicians are available for operation and routine maintenance. Sparker or arcer and air or gas gun systems are so complex that at least one well-trained technician or engineer would be needed for their use; therefore, leasing is not recommended.

99. Contracted geophysical services frequently appear outwardly expensive; however, detailed cost analyses involving factors such as equipment maintenance and personnel availability usually prove otherwise. Furthermore, geophysicists and/or engineers thoroughly familiar with the system and interpretation of the data can often obtain appreciably better survey results.

100. At the present time, oceanographic and marine geophysical activities are at an ebb for possibly several reasons, one of which is certainly the reduction in Federal support and Federal agency activities. This fact, combined with others such as increasing competition and continuing development of new models or systems, is certainly to the advantage of the CE. Since CE offices have had relatively little experience with acoustic profiling systems, there are indications that at least several manufacturers or geophysical firms would welcome opportunities to promote systems and demonstrate capabilities on an actual-cost basis. The current situation is considered essentially one of proven capabilities but declining activity in geophysical oceanography and mineral exploration geophysics as compared with only partially demonstrated capabilities and increasing activity and interest in engineering geology.

LITERATURE CITED

1. Bowers, R., "Modern Methods of Sub-Bottom Profiling Using Sonic Reflection Techniques," Science Progress, Vol 51, No. 201, 1963, pp 80-84.

2. Hersey, J. B., "Continuous Seismic Profiling," The Sea; Ideas and Observations, M. N. Hill, ed., Wiley & Sons, Inc., New York, Vol 3, 1963, pp 47-72.

3. Maries, A. C., and Beckmann, W. C., "A New Geophysical Method for the Exploration of Undersea Coalfields," The Mining Engineer, No. 4, Jan 1961, pp 262-276.

4. Shor, G. G., Jr., "Non-Explosive Profilers; Methods (Arcers, Sparkers, Boomers, Gas-Guns, Air-Guns, and Similar Devices)," International Dictionary of Geophysics, Pergamon Press, London, 1967, pp 1018-1021.

5. Smith, W. O., "Recent Underwater Surveys Using Low-Frequency Sound to Locate Shallow Bedrock," Geological Society of America Bulletin, Vol 69, No. 1, Jan 1958, pp 69-97.

6. McClure, C. D., et al., "Marine Sonoprobe System, New Tool for Geologic Mapping," American Association of Petroleum Geologists Bulletin, Vol 42, No. 4, Apr 1958, pp 701-716.

7. Edgerton, H. E., et al., "Sonar Probing in Narragansett Bay," Science, Vol 146, Dec 1964, pp 1459-1460.

8. Van Reenan, E. D., "Subsurface Exploration by Sonar Seismic Systems," Symposium on Soil Exploration, American Society of Testing Materials, Easton, Penn., 1964, pp 60-73

9. Edgerton, H. E., and Payson, H., "Sediment Penetration with a Short-Pulse Sonar," Journal of Sedimentary Petrology, Vol 35, No. 4, 1965, pp 876-880

10. Edgerton, H. E., and Hayward, G. G., "The 'Boomer' Sonar Source for Seismic Profiling," Journal of Geophysical Research, Vol 69, No. 14, Jul 1964, pp 3033-3042.

11. Moody, D. W., and Van Reenan, E. D., "High-Resolution Subbottom Seismic Profiles of the Delaware Estuary and Bay Mouth," Professional Paper 575-D, 1967, U. S. Geological Survey, Washington, D. C.

12. Lister, C. R. B., et al., "Sonar Reflection Profiling on the Columbia River and in Lake Washington," Northwest Science, Vol 41, No. 4, 1967, pp 152-154.

13. Luehrmann, W. H., "The Generation of Underwater Acoustic Impulses with Electrical Discharge Techniques," Marine, Non-Dynamite Energy Sources, A Symposium, Geophysical Society of Houston, Houston, Apr 1968.

14. Malloy, J., et al., "U. S. Coast and Geodetic Survey Geological Echo Profiling Program," International Hydrographic Review, Vol 41, Jul 1964, pp 37-44.

15. Luskin, B., et al., "Sub-Bottom Depth Recorder," Technical Report No. 16, Feb 1958, Lamont Geological Observatory, Palisades, New York.

16. Hoskins, Hartley, and Knott, S. T., "Geophysical Investigation of Cape Cod Bay, Massachusetts, Using the Continuous Seismic Profiler," The Journal of Geology, Vol 69, No. 3, May 1961, pp 330-340.

17. Hersey, J. B., et al., "Adaptation of Sonar Techniques for Exploring the Sediments and Crust of the Earth Beneath the Ocean," Radio and Electronic Engineer, Vol 26, No. 3, 1963, pp 245-250.

18. Caulfield, D. D., et al., "Improvements in the Continuous Seismic Profiler," Geophysics, Vol 30, No. 1, Feb 1965, pp 133-138.

19. Moore, D. G., "Acoustic-Reflection Reconnaissance of Continental Shelves: Eastern Bering and Chukchi Seas," Papers in Marine Geology: Shepard Commemorative Volume, The Macmillan Co., New York, 1964, pp 319-348.

20. Beckmann, W. C., et al., "Sub-Bottom Depth Recorder," Geophysics, Vol 24, No. 4, Oct 1959, pp 749-760.

21. Jones, H. J., "Dinoseis Marine Source," Marine, Non-Dynamite Energy Sources, A Symposium, Geophysical Society of Houston, Houston, Apr 1968.

22. Luskin, B., "The Par Air Gun," Marine, Non-Dynamite Energy Sources, A Symposium, Geophysical Society of Houston, Houston, Apr 1968.

23. Ewing, John, and Zaunere, Roger, "Seismic Profiling with a Pneumatic Sound Source," Journal of Geophysical Research, Vol 69, No. 22, Nov 1964, pp 4913-4915.

24. Clay, C. S., et al., "Seismic Profiling with a Hydroacoustic Transducer and Correlation Receiver," Journal of Geophysical Research, Vol 69, No. 16, Aug 1964, pp 3419-3428.

25. Krause, D. C., et al., "Seismic Profile Showing Cenozoic Development of the New England Continental Margin," Journal of Geophysical Research, Vol 71, No. 18, Sep 1966, pp 4327-4332.

26. Beckm[illegible], W. C., et al., "SDR Survey for Proposed Chesapeake Bay Crossing," Journal of the Surveying and Mapping Division, American Society of Civil Engineers, Vol 86, No. SU 2, Jul 1960, pp 19-31.

27. Curray, J. R., and Moore, D. G., "Pleistocene Deltaic Progradation of Continental Terrace, Costa de Nayarit, Mexico," Marine Geology of the Gulf of California, Tj. H. van Andel and G. G. Shor, Jr., eds., American Association of Petroleum Geologists, Tulsa, 1964, pp 193-215.

28. Smith, D. T., and Li, W. N., "Echo-Sounding and Sea-Floor Sediments," Marine Geology, Vol 4, 1966, pp 353-364.

29. Saucier, R. T., "Acoustic Subbottom Profiling Survey, Walter F. George Reservoir, Alabama-Georgia," Miscellaneous Paper No. S-69-32, Aug 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

30. Behrens, E. W., "Buried Pleistocene River Valleys in Aransas and Baffin Bays, Texas," Publication No. 9, 1963, The University of Texas, Institute of Marine Science, Port Aransas, Texas.

31. Curray, J. R., and Moore, D. G., "Facies Delineation by Acoustic-Reflection: Northern Gulf of Mexico," Sedimentology, Vol 2, 1963, pp 130-148.

32. Burke, Pearl, "Development of the Sonar Pinger," Potamology Research Project No. 5, n.d., U. S. Army Engineer District, New Orleans, CE, New Orleans, La.

33. Matthew, R. K., and Thompson, C. O., "Sparker Survey, Matagorda Ship Channel--Galveston Harbor, Texas," Jun 1961, Marine Geophysical Services Corporation, Houston, Texas.

34. Alpine Geophysical Associates, Inc., "Final Report, Geophysical Site Investigation for Two Dams on Ohio River in Vicinity of Mound City, Illinois and Smithland, Kentucky," Apr 1966, Norwood, New Jersey.

35. Earhart, Roy, "Sparker--Gas Exploder Survey, Arkansas River, Mile 302.0 to Mile 319.0," Apr 1962, Marine Geophysical Services Corporation, Houston, Texas.

36. Van Andel, T. H., and Sachs, P. L., "Sedimentation in the Gulf of Paria During the Holocene Transgression; a Subsurface Acoustic Reflection Study," Journal of Marine Research, Vol 22, No. 1, 1964, pp 30-50.

37. McMaster, R. L., and Lachance, T. P., "Seismic Reflectivity Studies on Northwestern African Continental Shelf: Strait of Gibraltar to Mauritania," The American Association of Petroleum Geologists Bulletin, Vol 52, No. 12, Dec 1968, pp 2387-2395.

38. Swift, D. J. P., and Lyall, A. K., "Origin of the Bay of Fundy, An Interpretation from Sub-Bottom Profiles," Marine Geology, Vol 6, No. 4, Aug 1968, pp 331-343.

A

Table 1

Some Operational and Performance Characteristics of Available Profiling Systems

Manufacturer or Operator and Name or Designation of System	Only or Dominant Frequency kcps	Intensity of Acoustic Output, db, or Stored Energy Level, J	Pulse Rate per sec	Pulse Length msec	Resolution ft	Depth of Penetration ft	Reference* or Source of Information	Availability**
Pingers (Piezoelectric Transducers)								
Edo Western Corp. Model 185 (Navy AN/UQN-IE)	12.0	61.5 db	10	0.9-1.2	2-3	120-150	36	P
Edo Western Corp. Model 419	7.0 or 3.5	107 db	--	0.2-30.0	0.5-1.5	30-150	Data Sheets	P
EG&G International, Inc. Pinger Probes	12.0 or 5.0	98 db	20(max.)	0.3-0.4	<1	45-90	Data Sheets	P
Kelvin Hughes America Corp. Echo Sounder	10.0	--	--	--	3	90	1	P
Ocean Research Equipment, Inc. Subbottom Profiling System	12.0-3.5	105-112 db	--	--	2	±100	Data Sheets	P
Ocean Sonics, Inc. Model OSR-119T/XD-5	8.0-3.5	--	--	0.02-1.0	±1-2	15-100±	Data Sheets	P
Pingers (Magnetostrictive Transducers)								
Brown and Ross, Inc. (Distr.) Elac Bottom Penetration Sounder	18.0	--	1-9	0.6-10.0	<1	90	Data Sheets	P
Magnolia Petroleum Co. Marine Sonoprobe	3.8	250 J	12	0.5	<0.5	30-60	6	O
Boomers (Electromechanical Transducers)								
EG&G International, Inc. High-Resolution Boomer	1.2-0.8	200-500 J	2.5	1.0	±1	20-200	Data Sheets	C
EG&G International, Inc. Standard Boomer	0.6-0.04	13,000 J(max.)	0.2-1.0	0.5(min.)	±10	1,000(max.)	8	P
Lister Enterprises Bubble Pulser	0.25	16 J	8(max.)	8.0	5-10	200+	Data Sheets	P
Sparkers and Arcers								
Alpine Geophysical Assoc., Inc. Sparker (a)	5.0-0.5	50 J	1+	--	5-15	300-400	38	C
Alpine Geophysical Assoc., Inc. Sparker (	0.6-0.25	100-400 J	1-16	<6	20-25	1,200	Data Sheets	C
Alpine Geophysical Assoc., Inc. Arcer	--	100,000 J	--	--	--	5,000+	Data Sheets	C
EG&G International, Inc. Sparkarray	0.120-0.08	105,000 J(max.)	--	--	50-100	7,000+	Data Sheets	P
General Oceanographics, Inc. Seismic Profiling System	10.0-0.00[illegible]	750-3,000 J	0.25-4	--	5-50±	1,000+	Data Sheets	C

Arcer	--	100,000 J	--	--	--	5,000+	Data Sheets	C
EG&G International, Inc. Sparkarray	0.120-0.06	165,000 J(max.)	--	--	50-100	7,000+	Data Sheets	P
General Oceanographics, Inc. Seismic Profiling System	10.0-0.004	750-3,000 J	0.25-4	--	5-50±	1,000+	Data Sheets	C
Hunter Limited Mark 3A Hydrosonde System	0.3-0.1	--	4	--	--	150	38	P
Lamont-Doherty Geological Obs. Subbottom Depth Recorder	5.0-0.3	--	1-4	--	--	600	20	O
Scripps Inst. of Oceanography Arcer or Sonic Profiler	0.5-0.2	3,000 J	1-2	--	20-30	600+	27	C
Southwest Research Institute Arcer	20.0-0.[illegible]	5,000 J	--	--	<10	3,000±	Pers. Comm.	[illegible]
Teledyne Industries Boomer System	1.0-0.125	5,000 J(max.)	4	8-[illegible]	10-50	300-2,000	13	C
Teledyne Industries [illegible] System	0.125-0.0[illegible]	160,000 J(max.)	0.25	8-23	--	15,000	13	C
Texas A&M University Sparker	--	50,000 J	--	--	--	5,000+	Pers. Comm.	O
U. S. Geological Survey Sparker System	--	13,000-160,000 J	--	--	--	--	Pers. Comm.	O
U. S. Coast & Geodetic Survey Sparker	0.[illegible]-0.[illegible]	1,000 J±	0.08-8.0	--	10-25	400+	14	O
U. S. Naval Undersea R&D Center Plasma System	4.0-0.0[illegible]	200,000 J(max.)	--	--	--	5,000+	Pers. Comm.	O
Western Geophysical Co. Sparker	--	100-400 J	0.25	--	--	1,500(max.)	Data Sheets	C
Western Geophysical Co. Arcer	--	80,000 J	0.23	--	--	6,000±	Data Sheets	C
Woods Hole Oceanographic Inst. Continuous Seismic Profiler	0.08-0.04	100,000 J(max.)	0.1-2	33	--	3,800+	18	O

Gas Guns

Lamont-Doherty Geological Obs. Repeatable Acoustic-Seismic Source	0.035	--	1-2	--	--	1,400+	20	O
Sinclair Oil & Gas Co. Dinoseis System	0.08-0.0[illegible]	--	--	[illegible]	>100	20,000±	21	O
Western Geophysical Co. Continuous Seismic Profiler	--	--	0.13	--	--	12,000+	Data Sheets	C

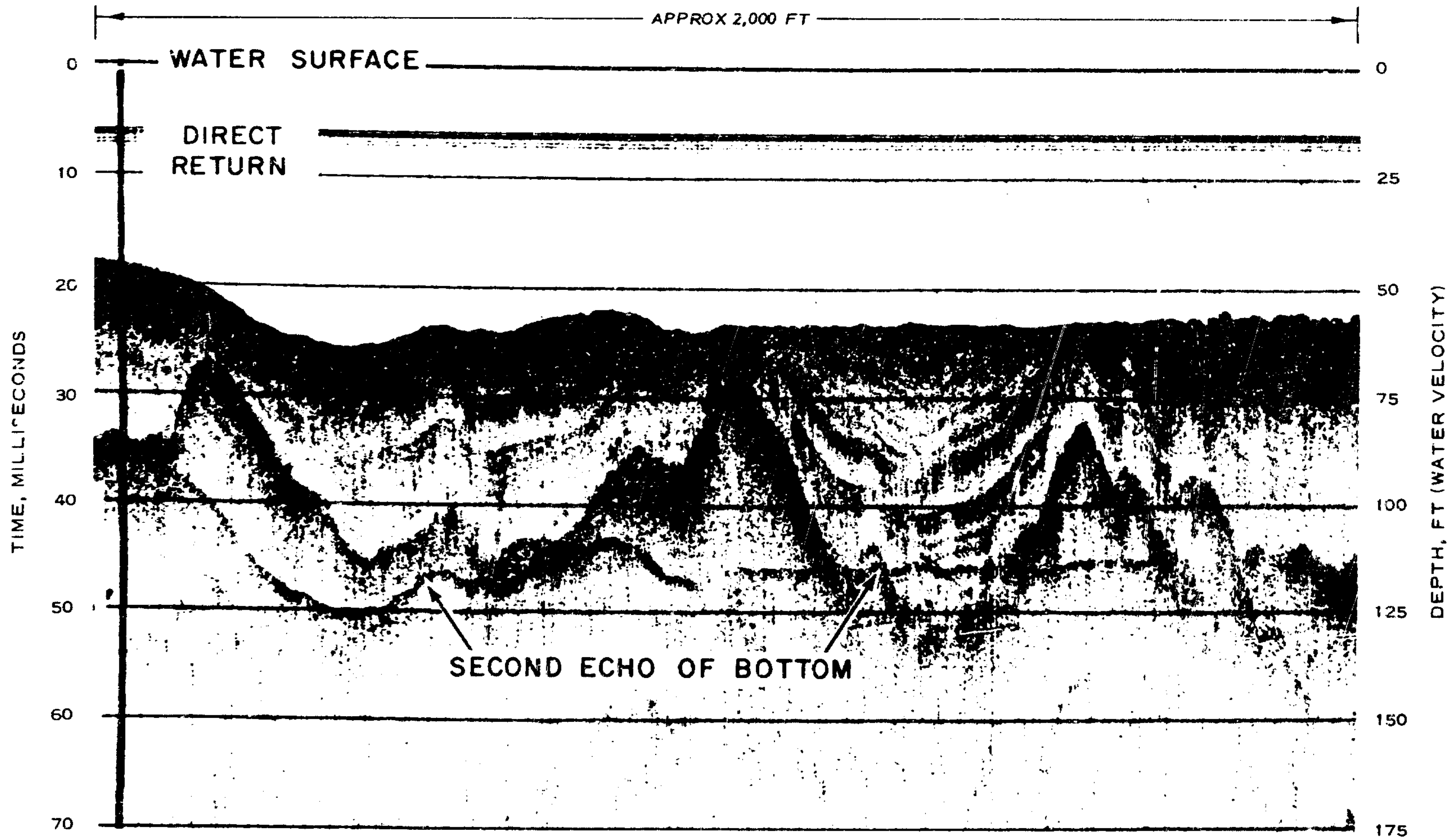
Air Guns

Bolt Associates, Inc. Marine Profiler	0.07-0.005	95-138 db	0.18-4	10(min.)	20-100+	400-10,000	22	P
Lamont-Doherty Geological Obs. Air Gun	--	120-125 db	0.1	--	--	2,000+	23	O
United Geophysical Corp. Shallow Water Air Gun System	0.2-0.005	--	--	<20	--	3,000±	Data Sheets	C

Miscellaneous

Raytheon Company, Inc. Hydroacoustic Source	0.2-0.2	15 & 1,500 J	0.06	1,000 & 10	12±	2,000+	24	C

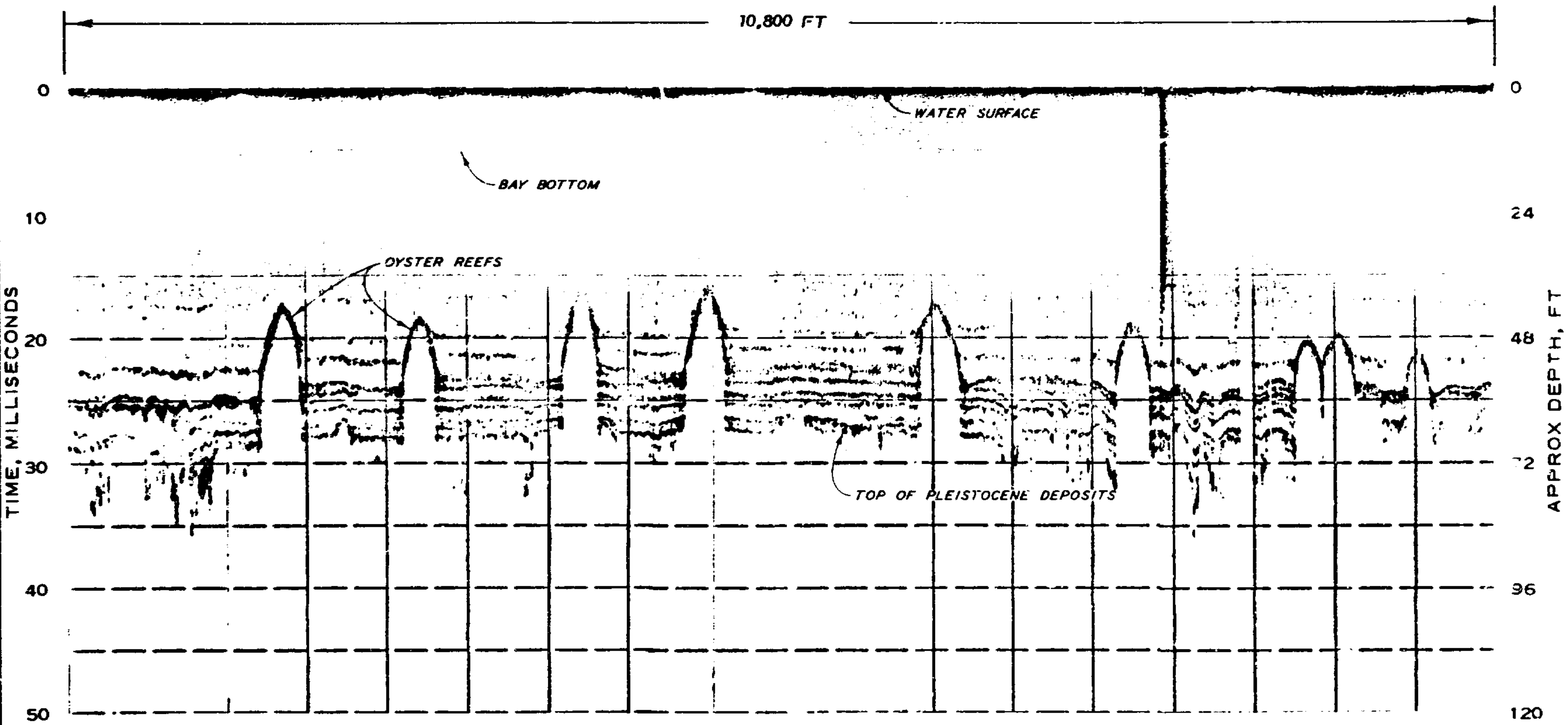
* Numbers refer to similarly numbered items in the Literature Cited at the end of the main text.
** P - available for purchase; C - available by contracted geophysical service; O - developed for internal use by pertinent organization or agency.



SOURCE: EG&G INTERNATIONAL, INC.
SYSTEM: 5-KCPS PINGER PROBE
LOCATION: BOSTON, MASS., HARBOR

EXAMPLE OF 5-KCPS PINGER SYSTEM RECORD

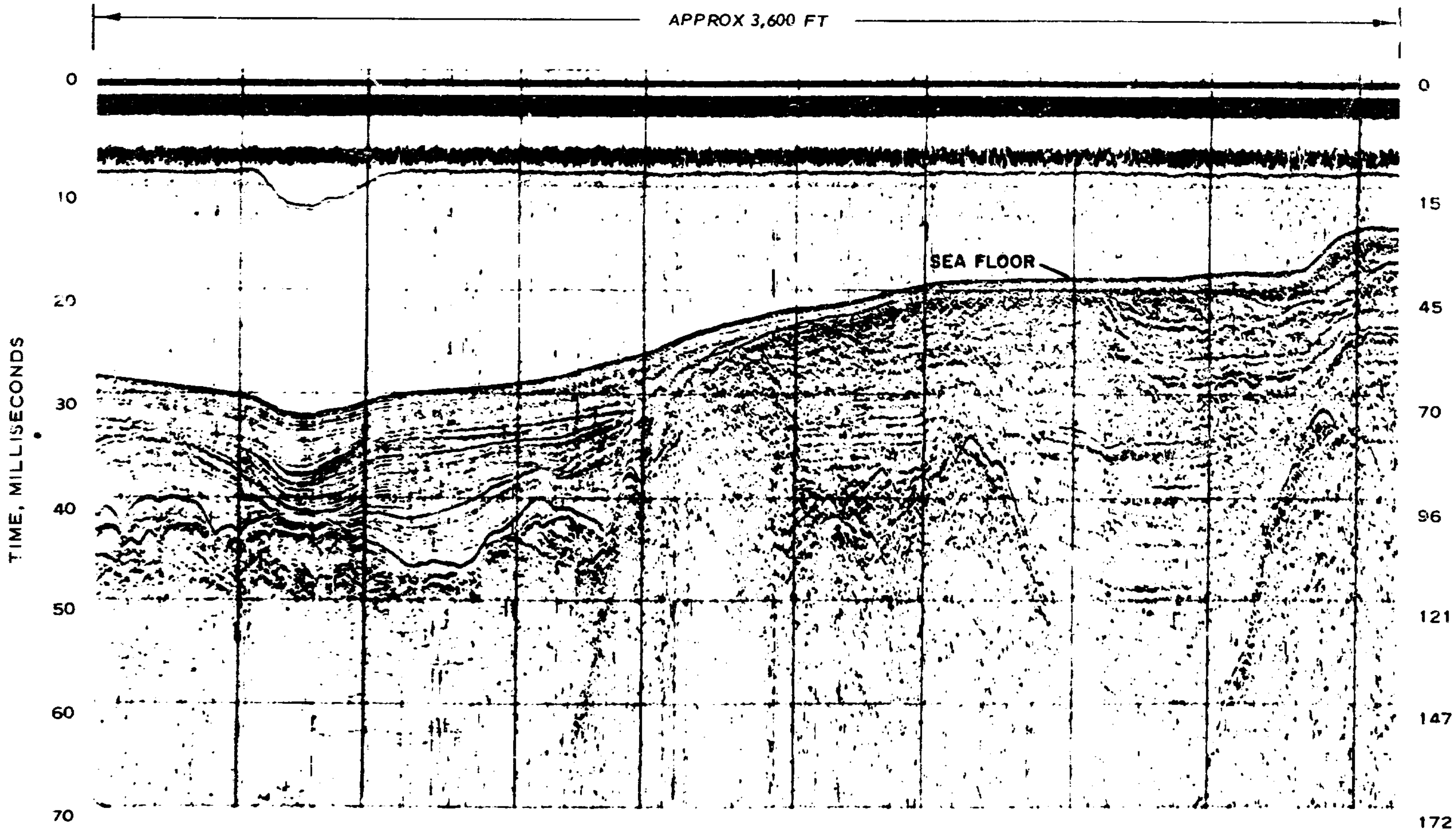
PLATE 1



SOURCE: SOUTHWEST RESEARCH INSTITUTE
OCEAN SCIENCE AND ENGINEERING LAB.
SYSTEM: 12-KCPS PINGER PROBE
LOCATION: CORPUS CHRISTI BAY, TEXAS

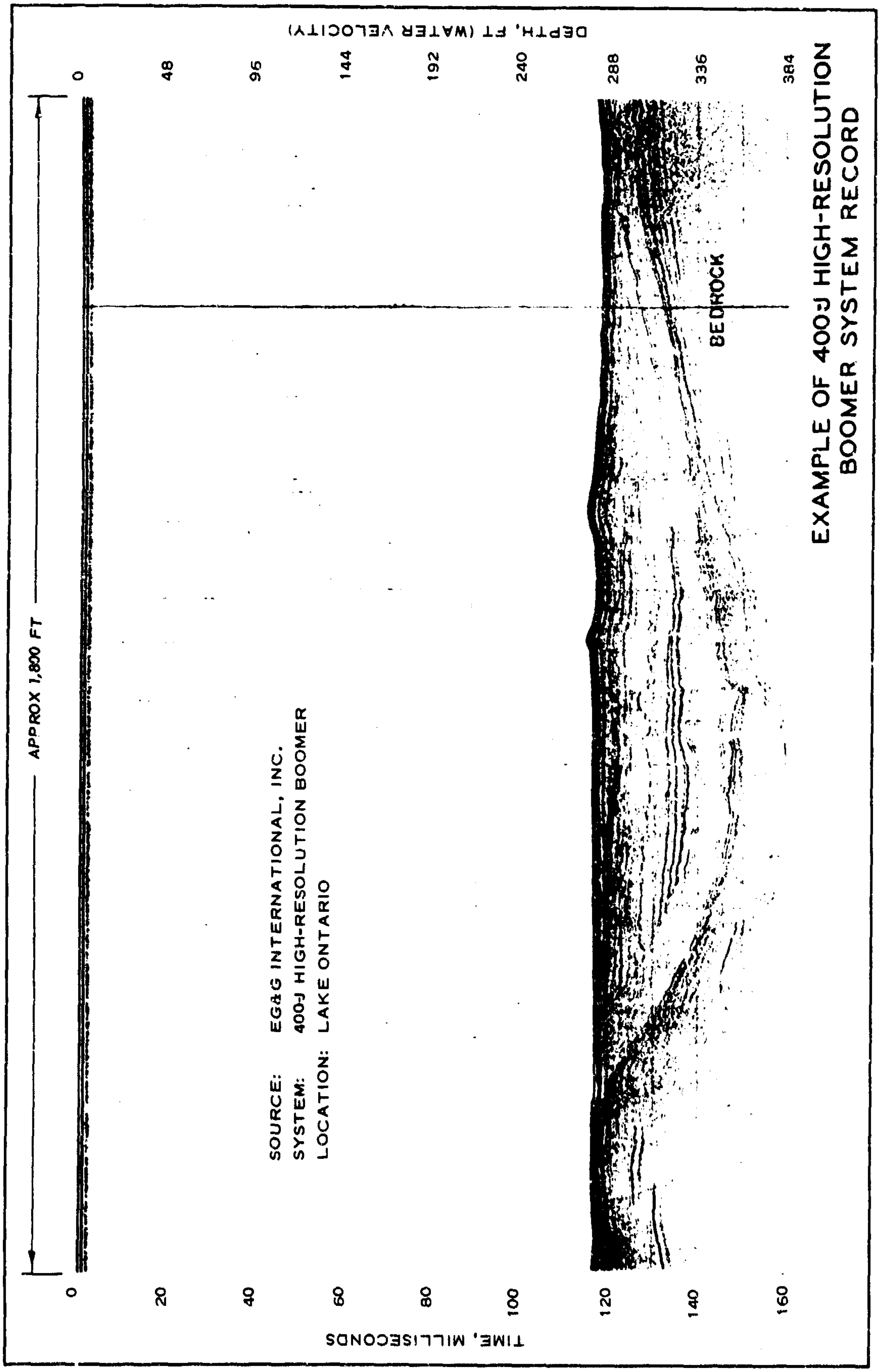
EXAMPLE OF 12-KCPS
PINGER SYSTEM RECORD

PLATE 2



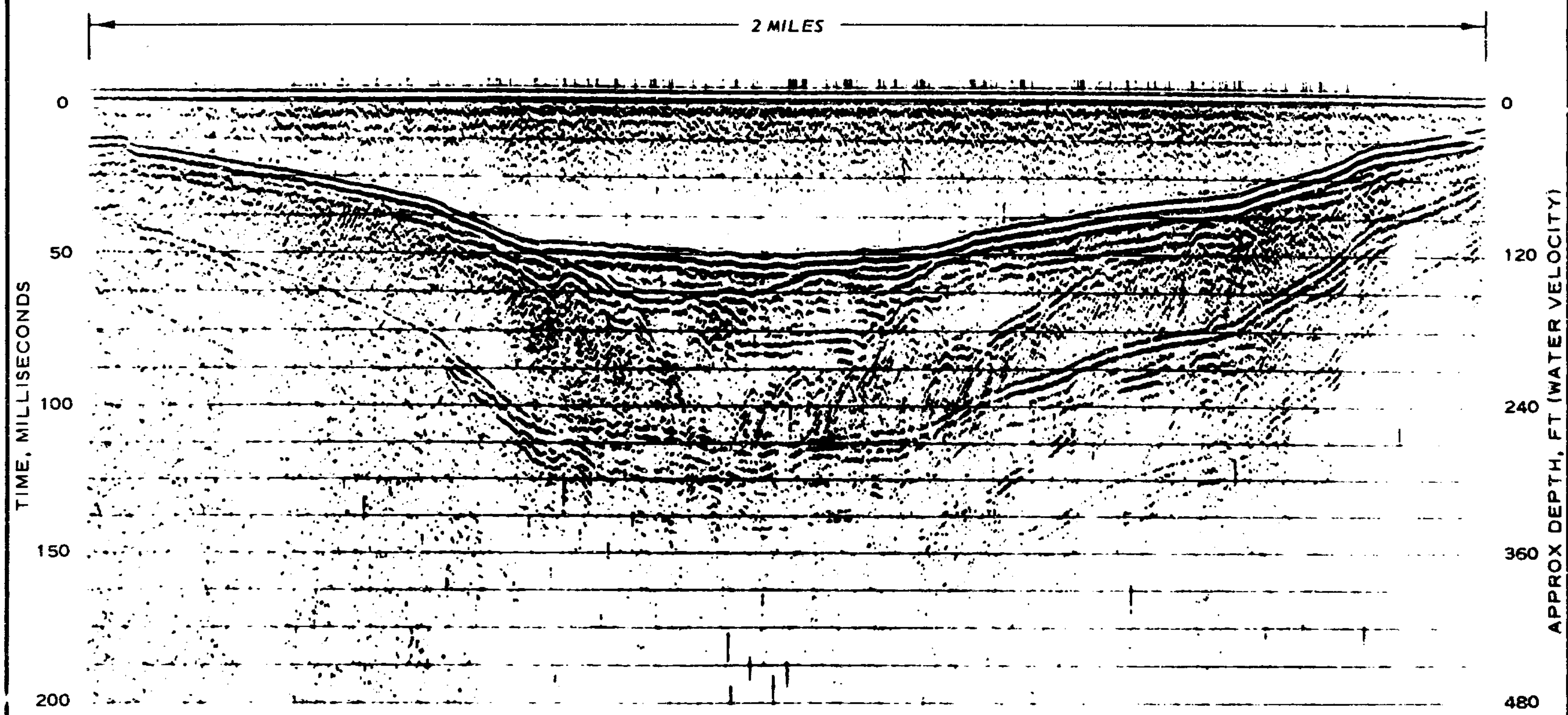
SOURCE: EG&G INTERNATIONAL, INC.
SYSTEM: 200-J HIGH-RESOLUTION BOOMER
LOCATION: LONG ISLAND SOUND

EXAMPLE OF 200-J HIGH-RESOLUTION BOOMER SYSTEM RECORD



EXAMPLE OF 400J HIGH-RESOLUTION BOOMER SYSTEM RECORD

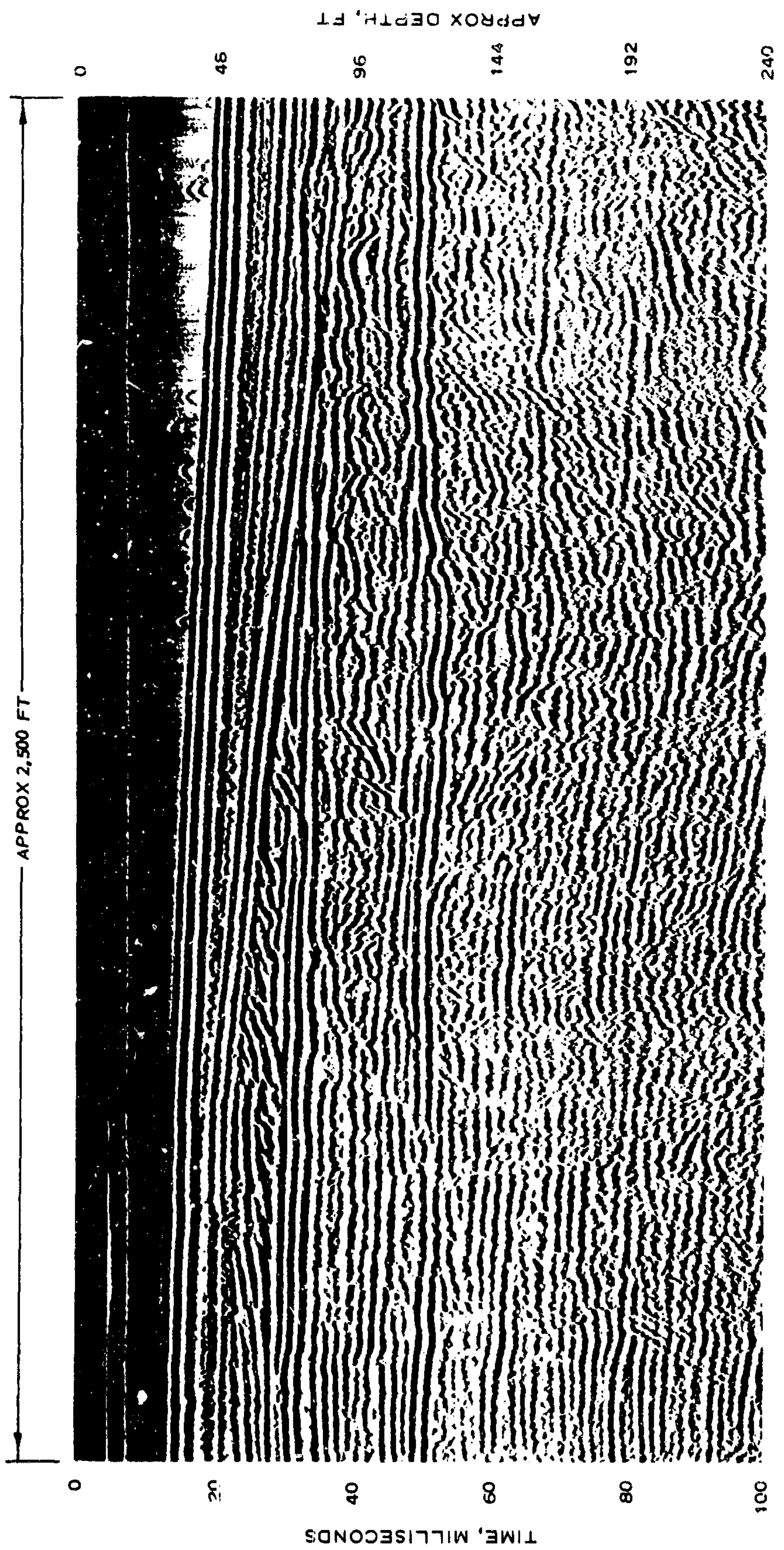
PLATE 4



SOURCE: EG&G INTERNATIONAL, INC.
SYSTEM: 1000-WATT-SEC BOOMER
LOCATION: BAY OF FUNDY

EXAMPLE OF STANDARD
BOOMER SYSTEM RECORD

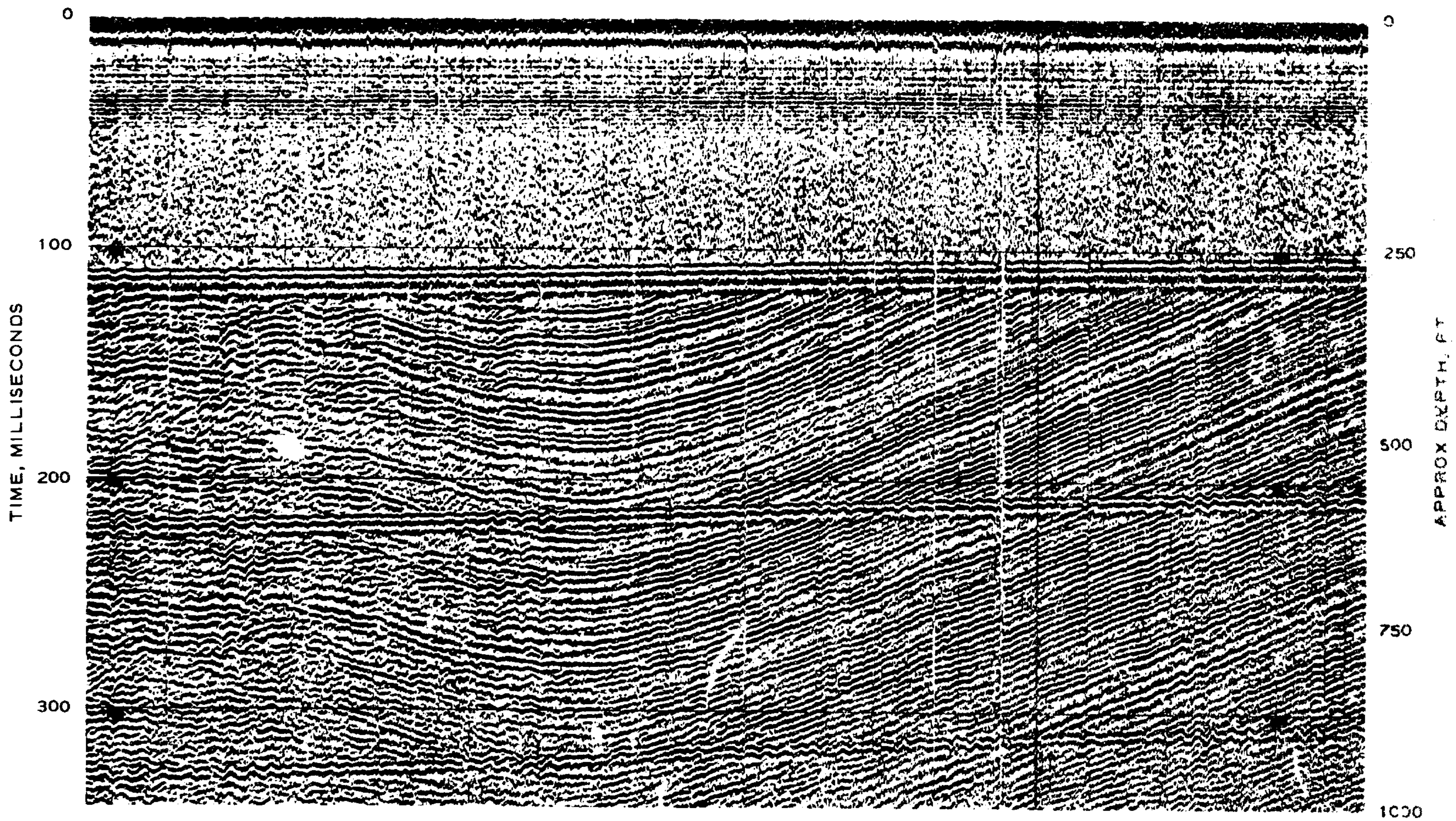
PLATE 5



EXAMPLE OF 900-J
ARCER SYSTEM RECORD

SOURCE: TELEDYNE EXPLORATION (GEO TECH)
SYSTEM: 900-J SUBOT ARCER
LOCATION: SOUTHEAST ASIA (OFFSHORE)

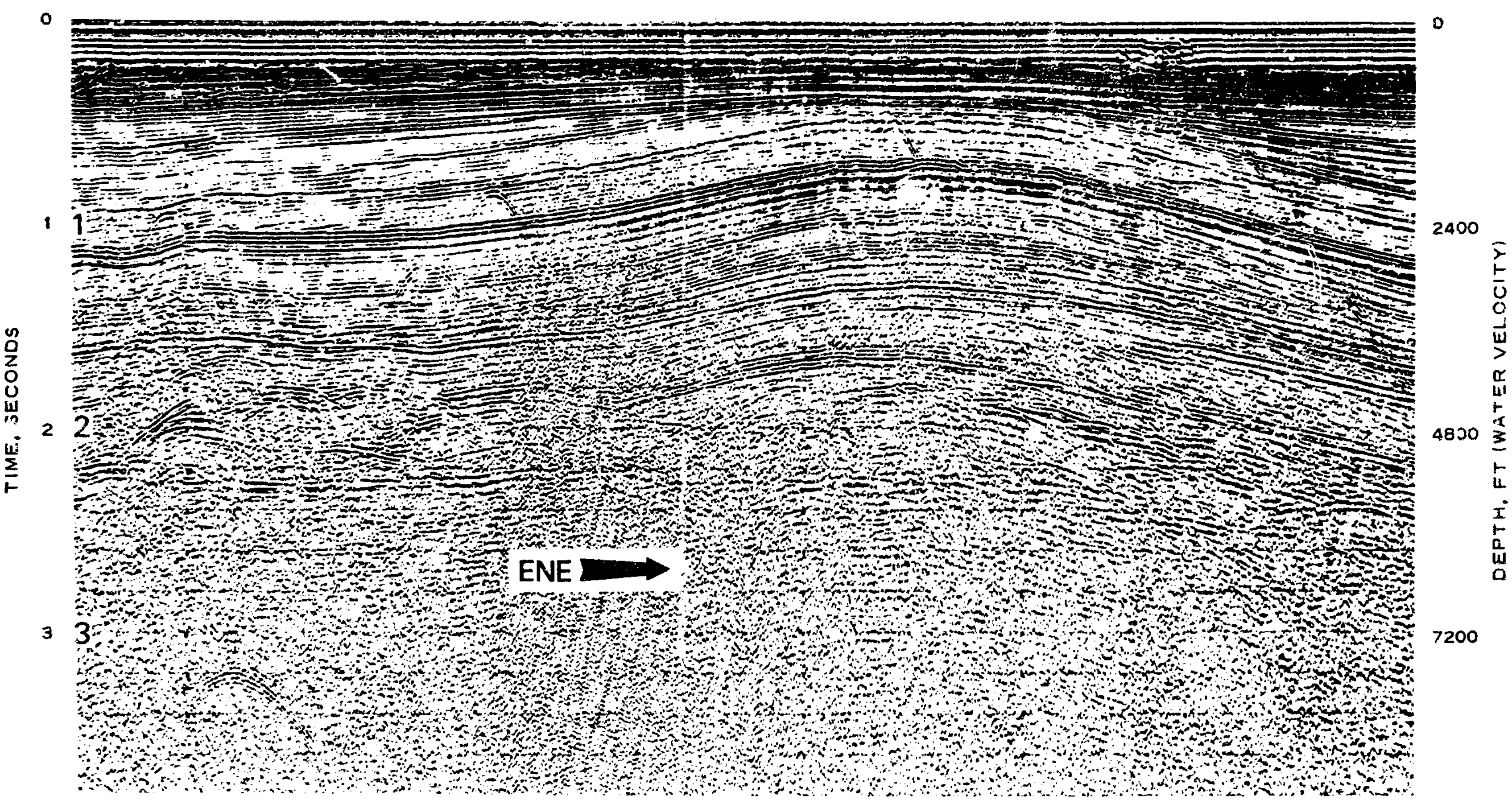
PLATE 6



SOURCE: TELEDYNE EXPLORATION (GEO TECH)
SYSTEM: 1500J SUBOT ARCER
LOCATION: SANTA BARBARA CHANNEL, CALIF.

EXAMPLE OF 1500-J
ARCER SYSTEM RECORD

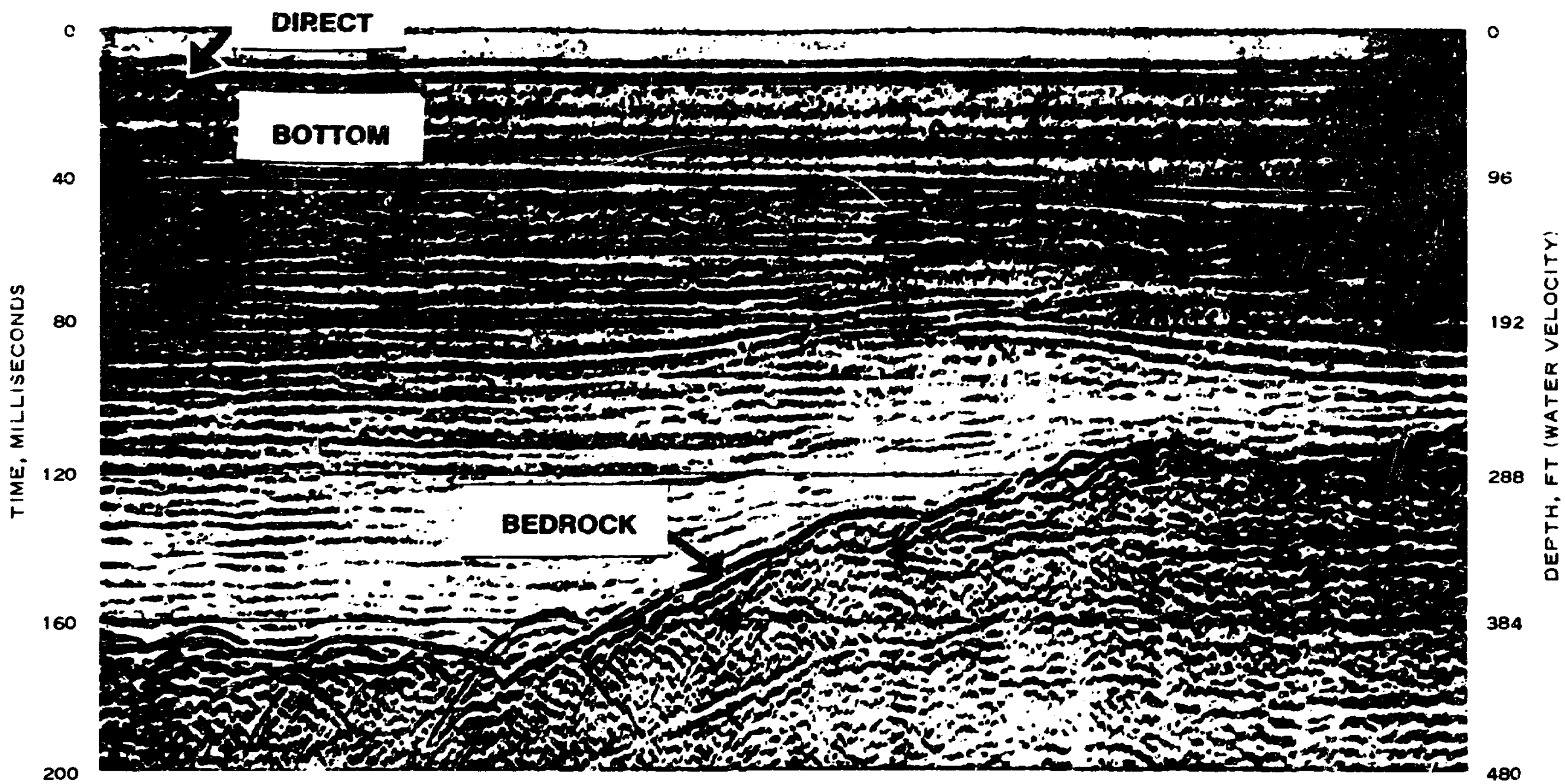
PLATE 7



SOURCE: TELEDYNE EXPLORATION (GEO TECH)
SYSTEM: 160,000J SSP SYSTEM
LOCATION: NORTH SEA

EXAMPLE OF 160,000-J
ARCER SYSTEM RECORD

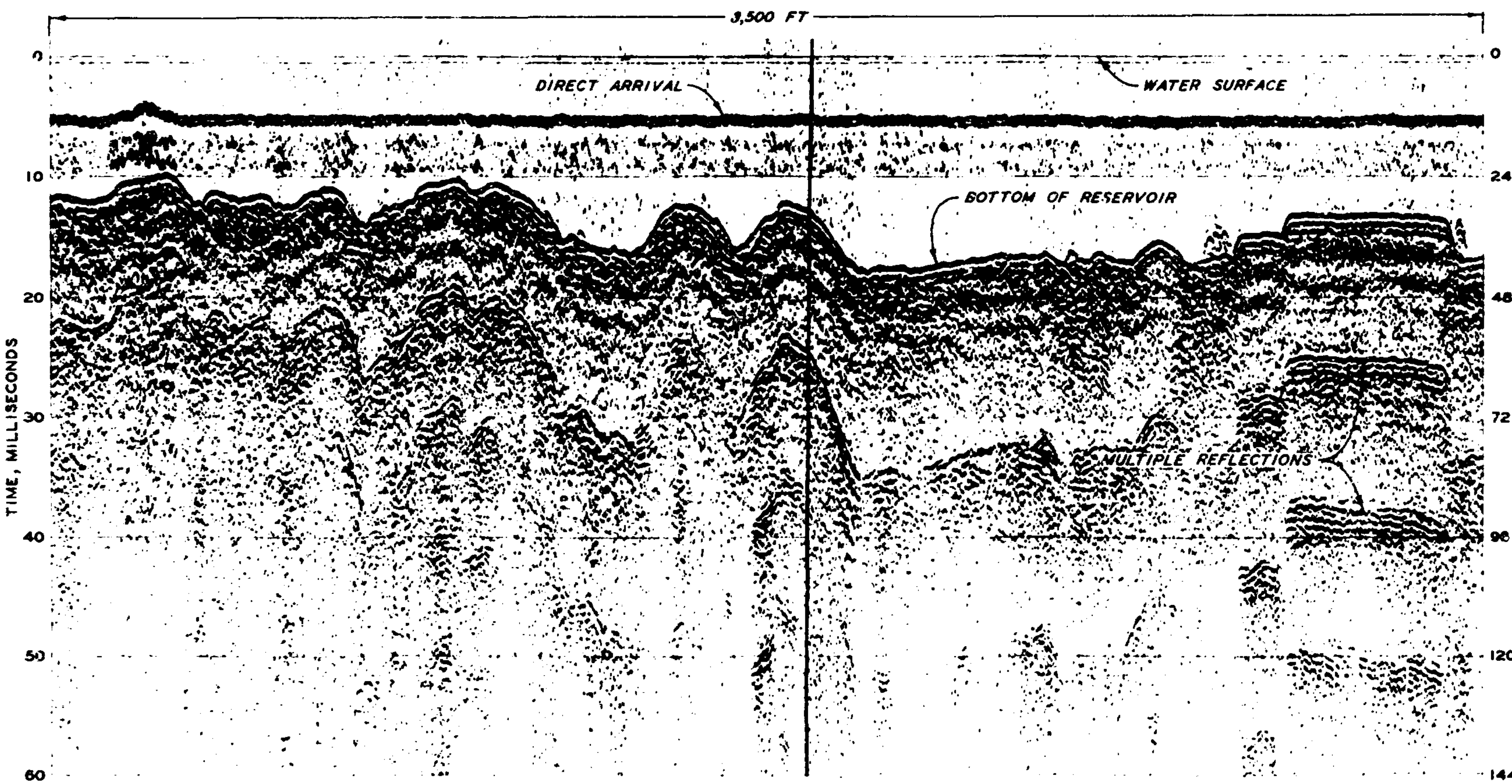
PLATE 8



SOURCE: BOLT ASSOCIATES, INC.
SYSTEM: 1-CU-IN. PAR AIR GUN
LOCATION: LONG ISLAND SOUND

EXAMPLE OF
AIR GUN SYSTEM RECORD

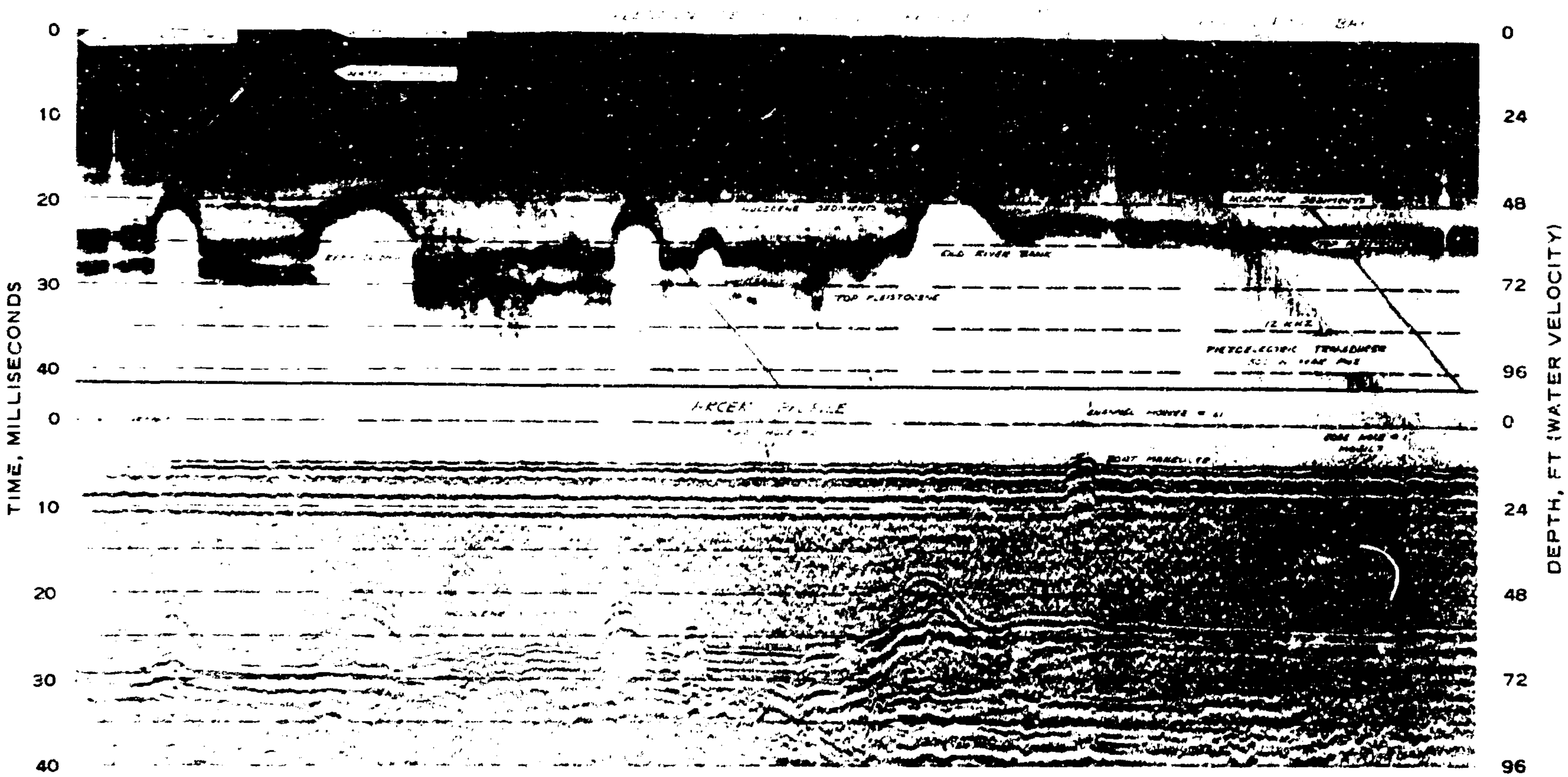
PLATE 9



SOURCE: REFERENCE 29
SYSTEM: EG&G HIGH-RESOLUTION BOOMER
LOCATION: WALTER F. GEORGE RESERVOIR, ALA.-GA.

EXAMPLE OF
MULTIPLE REFLECTIONS

PLATE 10



SOURCE: SOUTHWEST RESEARCH INSTITUTE
OCEAN SCIENCE & ENGINEERING LAB.

SYSTEM: 12-KCPS PINGER (TOP)
500-J ARCER (BOTTOM)

LOCATION: CORPUS CHRISTI BAY, TEXAS

COMPARISON OF PINGER
AND ARCER SYSTEM RECORDS

PLATE II

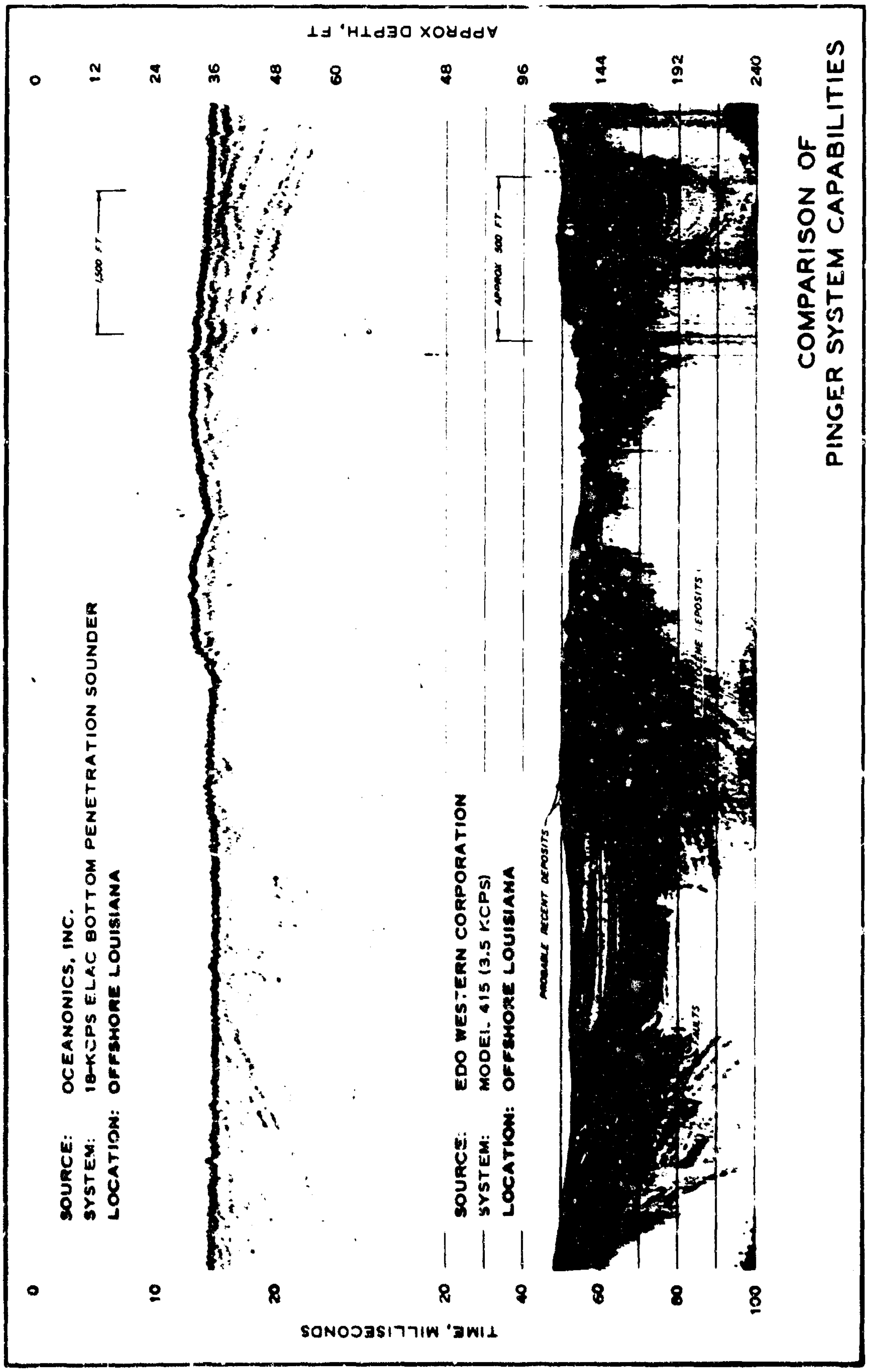
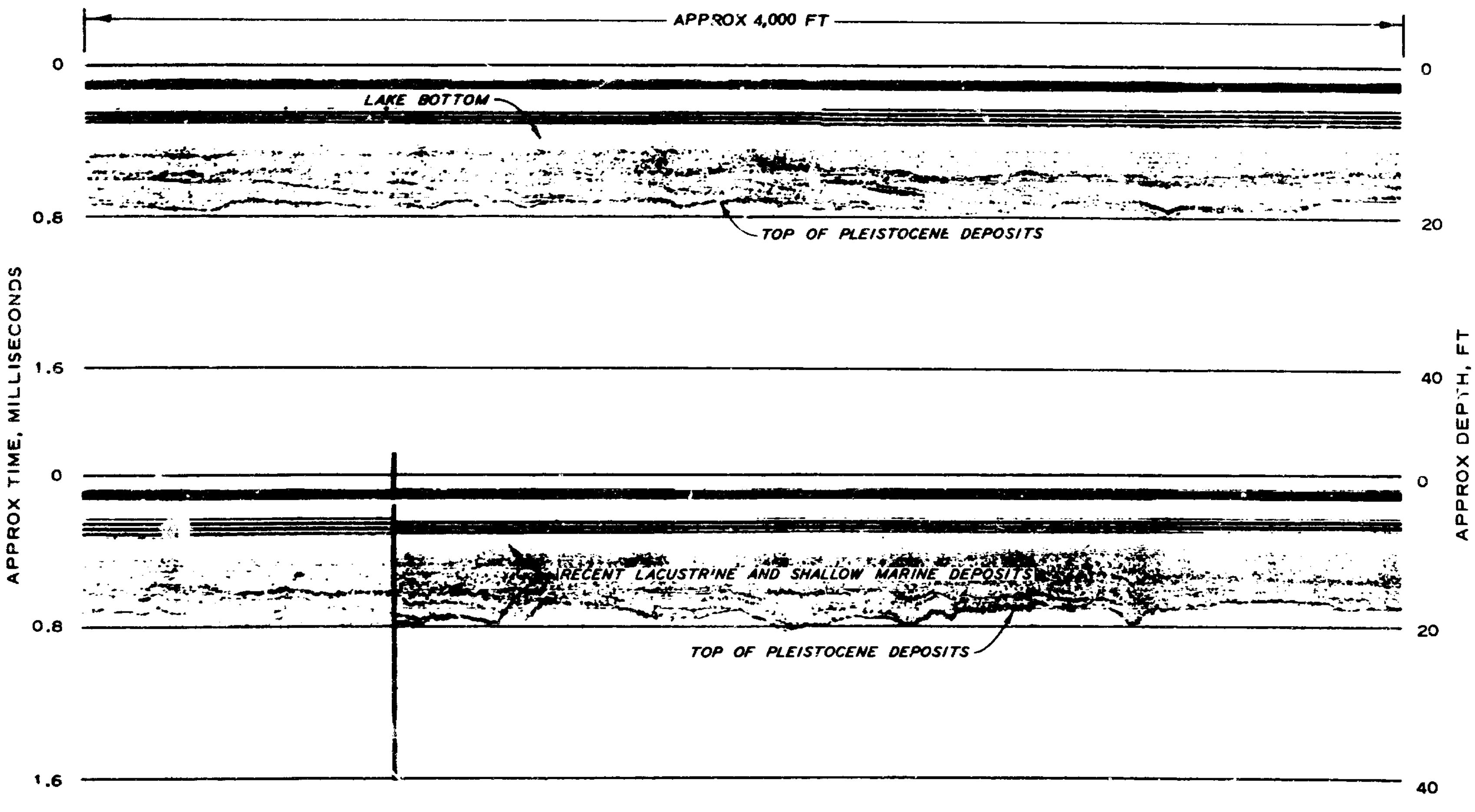

COMPARISON OF
PINGER SYSTEM CAPABILITIES
SOURCE: OCEANONICS, INC.
SYSTEM: 18-KCPS ELAC BOTTOM PENETRATION SOUNDER
LOCATION: OFFSHORE LOUISIANA
SOURCE: EDO WESTERN CORPORATION
SYSTEM: MODEL 415 (3.5 KCPS)
LOCATION: OFFSHORE LOUISIANA
1,500 FT
APPROX 500 FT
PROBABLE RECENT DEPOSITS
TIME, MILLISECONDS
APPROX DEPTH, FT
0
10
20
20
40
60
80
100
0
12
24
36
48
60
48
96
144
192
240

PLATE 12



SOURCE: WATERWAYS EXPERIMENT STATION
SYSTEM: EG&G 12-KCPS PINGER PROBE
LOCATION: EASTERN LAKE PONTCHARTRAIN, LA.

PINGER SYSTEM DELINEATION OF TOP OF PLEISTOCENE DEPOSITS

APPENDIX A

ADDRESS LIST FOR REFERENCED AGENCIES AND FIRMS

Alden Electronic & Impulse Recording Equipment Co., Inc.
1 Washington Street
Westboro, Massachusetts 01581
(617) 366-4467

Alpine Geophysical Associates, Inc.
65 Oak Street
Norwood, New Jersey 07648
(201) 768-8000

Bolt Associates, Inc.
10 Fitch Street
Norwalk, Connecticut 06855
(203) 866-4048

Brown and Ross, Inc.
770 Shore Walk
Lindenhurst, New York 11757
(516) 884-7171

Continental Oil Company
Ponca City, Oklahoma 74601
(405) 762-3456

Edo Western Corporation
2645 South Second West
Salt Lake City, Utah 84115
(801) 486-7481

EG&G International, Inc.
Geodyne Division
151 Bear Hill Road
Waltham, Massachusetts 02154
(617) 899-3710

Environmental Science Services Administration
Coast & Geodetic Survey
Washington Science Center
1180 Old Georgetown Road
Rockville, Maryland 20325
(301) 656-4088

General Oceanographics, Inc.
17911 Bascom Street
Irvine, California 92664
(714) 833-0282

Huntec Limited
1450 O'Connor Drive
Toronto 16, Canada
(416) 751-1244

Hydro Products Division
Dillingham Corporation
11803 Sorrento Valley Road
San Diego, California 92121
(714) 453-2345

Kelvin Hughes America Corp.
115 Eastern Avenue
Annapolis, Maryland 21404
(301) 267-8103

Lamont-Doherty Geological Observatory
Palisades, New York 10964
(914) 359-2900

Lister Enterprises
P. O. Box 101
University Station
Seattle, Washington 98105
(206) 325-5497

Marine Geophysical Services Corporation
Subsidiary of Alpine Geophysical Assoc., Inc.
6218 Evergreen Street
Houston, Texas 77036
(713) 774-7434

Muirhead Instruments, Inc.
1101 Bristol Road
Mountainside, New Jersey 07092
(201) 233-6010

Oceanonics, Inc.
Division of the Rucker Company
6210 Evergreen Street
Houston, Texas 77036
(713) 771-5731

Ocean Research Equipment, Inc.
P. O. Box 709
Falmouth, Massachusetts 02541
(617) 548-5800

Ocean Sonics, Inc.
125 Lomita Street
El Segundo, California 90245
(213) 322-6881

Raytheon Company, Inc.
Marine Products Division
213 East Grand Avenue
San Francisco, California 94080
(415) 598-7474

Scripps Institution of Oceanography
La Jolla, California 92038
(714) 453-2000

Sinclair Oil & Gas Company
Box 7190
Tulsa, Oklahoma 74105
(918) 245-1357

Southwest Research Institute
Ocean Science & Engineering Laboratory
P. O. Box 2604
Corpus Christi, Texas 78403
(512) 883-2921

States Electronic Corporation
Bludworth Marine Division
10 Adams Street
Linden, New Jersey 07036
(201) 925-8650

Teledyne Industries
Geotech Division
3401 Shiloh Road
Garland, Texas 75040
(214) 271-2561

Texas A&M University
Department of Oceanography
College Station, Texas 77843
(713) 845-3211

United Geophysical Corporation
The Bendix Corporation
2650 East Foothill Blvd.
Pasadena, California 91109
(213) 795-0421

U. S. Geological Survey
Office of Marine Geology & Hydrology
345 Middlefield Road
Menlo Park, California 94025
(415) 325-2411

U. S. Naval Undersea Research & Development Center
San Diego, California 92132
(714) 222-6311

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Roger T. Saucier

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13. ABSTRACT

Information from field tests, literature, and published data was gathered to establish the operating principles, capabilities and limitations, environmental restrictions, and availability of acoustic systems from the standpoint of conditions in the Lower Mississippi Valley. The acoustic systems are commonly classified according to the method by which the sound energy is produced, such as boomers, sparkers, and gas guns. Different degrees of resolution and penetration are achieved, largely because of differences in the frequency spectrum of the generated energy. However, because of inherent limitations, it is impossible to achieve both high resolution and deep penetration with any acoustic system. Either transducers or hydrophones of various designs are used to detect signals reflecting from subbottom horizons. Graphic recorders of various types are used with most acoustic profiling systems; however, magnetic-tape recording and signal processing is being accomplished with increasing frequency. Proper interpretation of acoustic subbottom profiles required an awareness of and possible corrections for scale variations caused by several factors, recognition of multiple reflections, an understanding of why reflections occur, and recognition of characteristic signatures. System selection for a particular survey requires a consideration of operational factors such as size and weight of equipment as well as environmental factors such as water salinity and depth. Previous applications and potential capabilities of acoustic systems include detection of buried erosion surfaces, correlation between borings, construction materials surveys, fault detection, and reservoir sedimentation studies.

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